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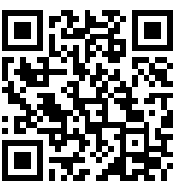

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RECEIVING MEASUREMENTS AND ATMOSPHERIC DISTURBANCES AT THE UNITED STATES NAVAL RADIO RESEARCH LABORATORY, BUREAU OF STANDARDS, WASHINGTON, SEPTEMBER AND OCTOBER, 1922*

By

L. W. Austin

(United States Naval Radio Research Laboratory, Washington, D.C.)

(Communication from the International Union for Scientific Radio Telegraphy)

The observations are taken according to the method briefly described in the Proceedings of The Institute of Radio Engineers for the month of June.

Radio Central on Long Island has proved to be the most satisfactory of the American stations for comparison purposes, as Annapolis and New Brunswick are too close for measurements with the telephone comparator on the low antenna, while Sayville and Marion have shown themselves somewhat variable as received at the laboratory.

The small table shows the ratios of the various averages, and indicates the disappearance of the summer conditions of strong afternoon fading and severe disturbances. It is seen that the extreme fading persists later with the shorter wave station, and it will be remembered that it began earlier in May and June.

The field intensities, 2 micro-volts per meter, given in a number of places in the tables, lie at the lower limit of the telephone comparator, and are to be considered approximations. Such signals were marked "too weak to measure" in former reports.

The signal measurements in the forenoon still indicate field intensities of approximately twice the calculated values.

The calculated intensities for the signals, assuming 480 amperes at Lafayette and 380 amperes at Nauen, are

$$E\,(\text{Lafayette}) = 31.5 \cdot 10^{-2} \text{ volts/meter}$$
$$E\,(\text{Nauen}) = 15.3 \cdot 10^{-2} \text{ volts/meter}$$

* Received by the Editor, December 4, 1922

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FIELD INTENSITY OF LAFAYETTE AND OF DISTURBANCES ($\lambda = 23{,}400$ m.) IN SEPTEMBER, 1922, IN MICRO-VOLTS PER METER

Date	10 A. M.		3 P. M.	
	Signal	Disturbances	Signal	Disturbances
1	80.0	200	50.0	1,000
2	90.0	300	....	....
5	100.0	200	60.0	80
6	80.0	100	50.0	200
7	60.0	300	50.0	400
8	50.0	200	....	....
9	70.0	150	....	....
11	80.0	200	....	....
12	60.0	150	40.0	300
13	95.0	100	35.0	300
14	85.0	100	40.0	400
15	75.0	80	....	....
16	80.0	30	....	....
18	65.0	50	....	....
19	60.0	40	....	....
20	75.0	60	50.0	60
21	110.0	40	55.0	80
22	70.0	20	....	....
23	100.0	30	45.0	60
25	*	20	*	60
26	*	20	55.0	150
27	65.0	40	....	....
28	*	50	45.0	150
29	70.0	150	35.0	300
30	85.0	100	45.0	300
Average	77.5	109	46.8	256

* Not heard.
.... Not taken.

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FIELD INTENSITY OF NAUEN AND OF DISTURBANCES ($\lambda = 12{,}500$ m.) IN SEPTEMBER, 1922, IN MICRO-VOLTS PER METER

Date	10 A. M.		3 P. M.	
	Signal	Disturbances	Signal	Disturbances
1	26.0	100	*	80
2	30.0	80	....	....
5	26.0	60	*	40
6	*	60	2.0	60
7	34.0	40	25.0	80
8	25.0	100	....	....
9	43.0	40	....	....
11	34.0	60	....	....
12	38.5	80	2.0	100
13	60.0	50	15.0	100
14	43.0	50	2.0	300
15	30.0	30	....	....
16	30.0	30	....	....
18	6.0	20	2.0	600
19	26.0	15	....	....
20	30.0	30	25.0	30
21	38.5	20	*	40
22	26.0	80	*	100
23	56.0	60	2.0	200
25	30.0	100	....	....
26	38.5	10	30.0	80
27	34.0	15	13.0	200
28	34.0	15	13.0	50
29	26.0	60	17.0	80
30	26.0	40	17.0	100
Average	33.8	49.8	12.7	131.7

* Not heard.
. . . Not taken.

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FIELD INTENSITY OF LAFAYETTE AND OF DISTURBANCES ($\lambda = 23{,}400$ m.) IN OCTOBER, 1922, IN MICRO-VOLTS PER METER

Date	10 A. M.		3 P. M.	
	Signal	Disturbances	Signal	Disturbances
2	75.0	50	20.0	200
3	35.0	50	40.0	150
4	75.0	80	....	....
5	60.0	100	35.0	200
6	*	100	30.0	600
7	*	80	50.0	200
9	*	40	70.0	100
10	*	40	60.0	80
11	*	30	55.0	80
12	85.0	15	50.0	150
13	*	40	60.0	50
14	*	50	*	100
16	*	80	60.0	150
17	*	40	40.0	200
18	95.0	30	50.0	80
19	*	30	55.0	60
20	*	40	50.0	100
21	95.0	30	45.0	80
23	*	30	40.0	60
24	*	15	45.0	300
25	*	15	70.0	40
26	*	300	45.0	300
27	*	150	25.0	400
28	*	150	20.0	200
30	*	80	19.0	50
31	44.0	60	50.0	130
Average	70.5	66.3	45.2	162

*Not heard.
.... Not taken.

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FIELD INTENSITY OF NAUEN AND OF DISTURBANCES ($\lambda = 12{,}500$ m.) IN OCTOBER, 1922, IN MICRO-VOLTS PER METER

	10 A. M.		3 P. M.	
Date	Signal	Disturbances	Signal	Disturbances
2	26.0	20	2.0	80
3	26.0	30	8.5	50
4	38.5	30	....	....
5	26.0	40	13.0	80
6	26.0	50	13.0	300
7	38.5	30	30.0	50
9	34.0	20	*	60
10	34.0	15	21.0	40
11	30.0	10	26.0	30
12	26.0	8	17.0	40
13	26.0	15	30.0	20
14	*	20	17.0	60
16	43.0	30	34.0	50
17	30.0	20	21.0	50
18	38.5	15	26.0	30
19	*	8	26.0	30
20	38.5	10	21.0	60
21	34.0	10	26.0	50
23	34.0	8	21.0	30
24	*	8	21.0	100
25	26.0	80	21.0	40
26	21.0	100	17.0	150
27	21.0	30	*	100
28	4.0	50	....	....
30	17.0	40	9.3	30
31	32.0	20	4.0	43
Average	28.7	27.6	19.3	65.6

* Not heard.
.... Not taken.

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SEPTEMBER

	Signal P. M. / A. M.	Disturbance P. M. / A. M.	A. M. Signal / Disturbance	P. M. Signal / Disturbance
$\lambda = 23{,}400$	0.604	2.34	0.771	0.183
$\lambda = 12{,}500$	0.376	2.74	0.679	0.096
OCTOBER				
$\lambda = 23{,}400$	0.641	2.45	1.06	0.279
$\lambda = 12{,}500$	0.672	2.38	1.04	0.294

SUMMARY: Field intensities of the signals from the Lafayette and Nauen stations, together with the simultaneous strength of the atmospheric disturbances, are given for September and October, 1922.

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THE OSCILLATION ENGINEERING DESIGN OF SUBMARINE ACOUSTIC SIGNALING APPARATUS

By

Walter Hahnemann

(Signal Gesellschaft, Kiel, Germany)

In submarine sound signaling, we are concerned with phenomena which are highly similar to those of radio telegraphy. In each case the problem is to transmit energy for signaling or any other similar purpose from a transmitting station to a receiving station. Accordingly, there are transmitters and receivers in submarine signaling, exactly as in radio telegraphy. At the transmitter, the energy in question must be produced in the form of convenient oscillations, and then transferred to a suitable radiating system (sound antenna), from which it is imparted to the medium. At the receiver, a similar radiating system must pick up the energy from the medium, and must then transform it into such a form that it will give perceptible indications to the observer on a suitable indicating instrument. This process, in the case of radio telegraphy, is very well known. In this paper we shall describe the acoustic or oscillation engineering design of typical transmitting and receiving apparatus for submarine signaling.

Altho acoustics is a much older subject than radio telegraphy, the necessity for solving engineering problems in the field of oscillations first arose in radio telegraphy, and before the necessary oscillation engineering basic laws were used clearly and consciously in the field of acoustic engineering. The application of these laws to the field of submarine signaling engineering has taken place only during the last ten years. That is, the basic laws of oscillation engineering were first necessarily developed in radio telegraphy, the elder brother of submarine acoustic engineering, and before the necessary investigations could be carried out in the field of submarine signal engineering. It is, therefore, not accidental that, for example, here in the

* Received by the Editor, November 10, 1922. Presented before The Institute of Radio Engineers, New York, November 21, 1922. Translated from the German by the Editor.

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SEPTEMBER

	Signal P. M. / A. M.	Disturbance P. M. / A. M.	A. M. Signal / Disturbance	P. M. Signal / Disturbance
$\lambda = 23{,}400$	0.604	2.34	0.771	0.183
$\lambda = 12{,}500$	0.376	2.74	0.679	0.096
OCTOBER				
$\lambda = 23{,}400$	0.641	2.45	1.06	0.279
$\lambda = 12{,}500$	0.672	2.38	1.04	0.294

SUMMARY: Field intensities of the signals from the Lafayette and Nauen stations, together with the simultaneous strength of the atmospheric disturbances, are given for September and October, 1922.

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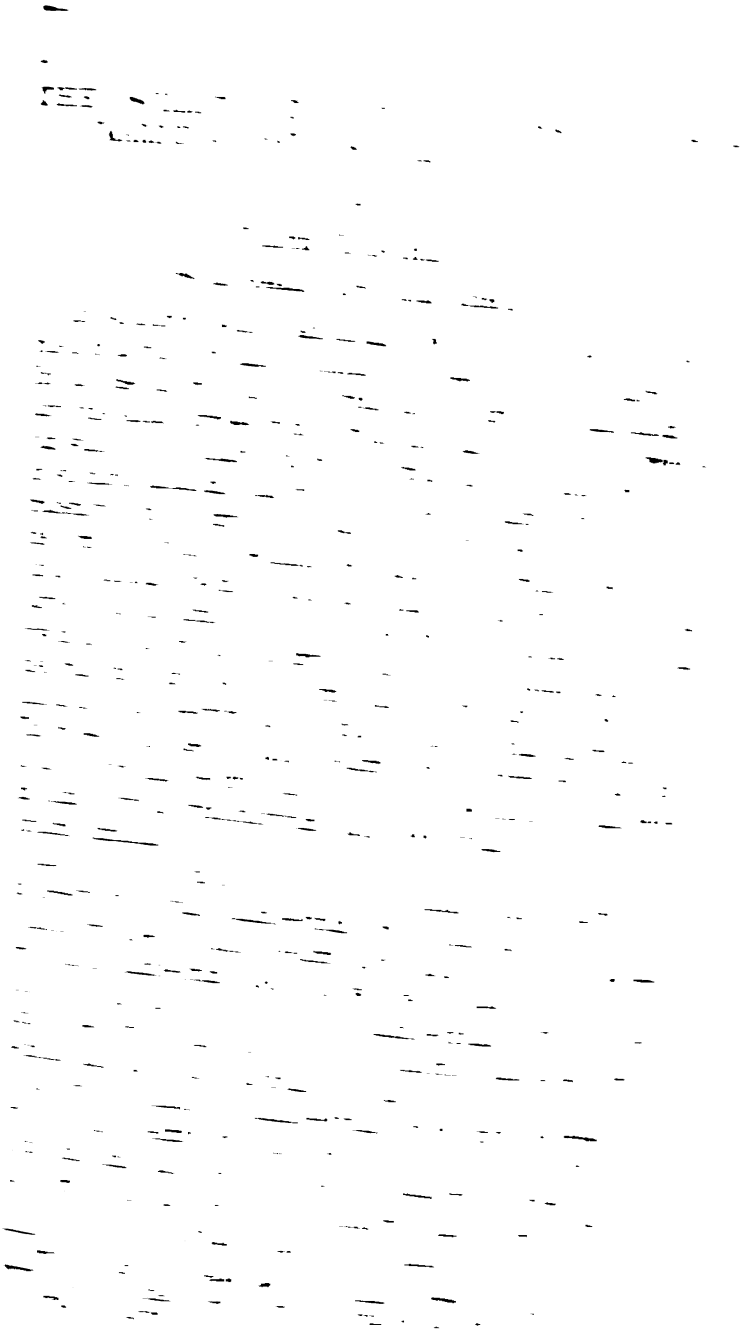

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United States a radio engineer and investigator of the eminence of Professor Fessenden has produced the submarine signaling transmitters which are known by his name. Similarly, in Germany, the development of submarine signaling apparatus first became possible thru the experience and knowledge which we had gained in the field of radio telegraphy. We have here an excellent sample of how scientific advances in one field may be of great benefit to other fields.

At this point I wish to remark that this continual progress in submarine signaling apparatus is having a beneficial influence on related fields, as, for example, in the application of the same principles to apparatus for signaling thru the air by sound methods which are now being investigated along analogous lines. In particular, we have already succeeded in applying the results of submarine signaling investigations satisfactorily to one of the most important aerial signaling instruments, namely, the telephone. In this way we acoustic engineers hope to recompense our closely related field—radio telegraphy—to some extent for what it has done for us, and for this reason we feel in duty bound to investigate telephonic problems.

A simple and most generally employed example of oscillatory systems for transmitting and receiving in radio telegraphy is that consisting of two coupled oscillatory circuits. This familiar arrangement is shown in Figure 1. At the left we see the trans-

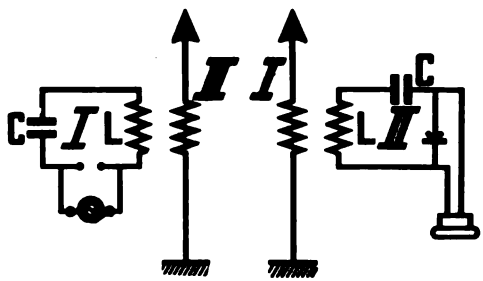

FIGURE 1

mitter, with the receiver at the right. Both transmitter and receiver consist of two oscillating circuits, one of which is a closed circuit, and the other consists of the radiating system or antenna. At the transmitter, the energy is transformed into oscillations in the closed circuit: circuit 1. In addition to the oscillation generator proper, which consists of a generator and spark gap in the illustration, the primary circuit of the transmitter contains

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the capacity C and the inductance L. The antenna is coupled to the inductance L thru a suitable coil and forms the second oscillatory circuit of the transmitter. The receiver is quite similar. Energy is absorbed from the electric magnetic field by the antenna 1 and is transferred thru a suitable coupling to the secondary circuit 2, which also consists of a capacity C and an inductance L, and which further contains in this case a detector and telephone to give suitable indications of the incoming energy. Thus, in both cases we have a coupling of a radiating system with a closed oscillatory circuit. The closed circuits serve for the transformation of energy, and the radiating systems for the transfer of energy to or from the medium.

We shall now show how the same oscillation engineering design is applied to a typical submarine signaling system. Before doing this, we must mention the mechanical and acoustic analogues of closed electrical oscillatory circuits and of radiating antennas.

In Figure 2 there is shown schematically a well-known acoustic oscillation system: the tuning fork. The dotted lines show the way in which the shape of the tuning fork is altered when prongs *b b* are set into oscillation in any way. The points *a a* of the fork, however, remain at rest, and are therefore nodal points, whereas the remaining portions of the fork, and particularly the handle at the middle point of the fork *c*, also swing up and down. If, for example, the prongs *b b* move inward, the point *c* and the handle will move downward.

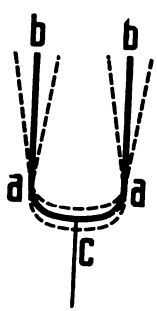

FIGURE 2

For our purpose, it seemed natural to use the tuning fork which is already generally known in acoustics, or a similar system as, for example, a reed. This was accordingly done. It very soon appeared, however that the desired results could not be obtained in this way. The reason for this is the following: In

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these systems, *mass and elasticity are not separated from each other*, but instead are distributed over the entire system. An electrical analogue of this is well known to all radio engineers, and consists of coils oscillating in their own free period and in which inductance and capacity are also distributed over their entire surface. Such systems are, in general, unsuitable for use as closed circuits. Thus, if we apply an exciting or retarding force to such oscillatory systems, they tend to shirk the work by correspondingly shifting their nodal points. We were therefore forced to discover a mechanical acoustic oscillatory system in which, as far as possible, elasticity and mass were fully separated from each other, exactly as in the usual closed electrical systems with concentrated inductance and capacity. Only after we had actually obtained such systems were we ready to solve the problems which faced us.

The arrangement of such a closed oscillatory system with separated mass and elasticity is shown in Figure 3. It consists of two masses (represented by the squares) and an elastic member connecting them (represented by the zig-zag line). A mechanical oscillation system consisting of one mass and elastic element has been previously frequently considered as typical of mechanical oscillatory systems. This is, however, not the general case of a closed mechanical-acoustic oscillatory system, but only a special case of the more general form shown in the figure, from which it is assumed, sometimes unconsciously, that one of the masses is infinitely large.

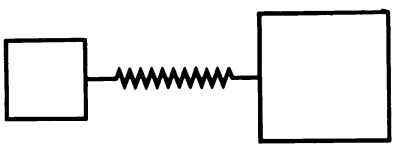

FIGURE 3

The generalized system consists rather of two masses and a single elastic element joining them. Assuming that such a system does not give out any energy, it oscillates about its center of mass. It follows, therefore, that the amplitudes as well as the velocities of both masses are in inverse proportion to their respective masses, from which it also follows that the energy of oscillation in each of the masses is inversely proportionately to the mass. These are very important facts. For example, this property of an oscillatory system leads to the possibility of a mechanical-acoustic transformation without the use of a lever.

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The lever—the mechanical analogue of the electrical transformer—can be applied only in a limited way at frequencies of about 1,000 cycles per second and more, such as are under consideration, because at such frequencies it is only too likely to become an oscillatory system itself, and thereby loses more or less of its property of transforming amplitudes of vibration. Furthermore, it is not possible at such high frequencies to use the usual forms of pivoted links.

A practical attempt to produce such oscillatory systems for the high frequency of 1,000 cycles which is used in practice soon showed that elastic springs, having the necessary large elastic force, could not be built to have a sufficiently small mass. We had to employ a new arrangement of an elastic element which combined the smallest possible mass with the greatest possible elastic strength. This was the longitudinally strained rod or tube. In Figure 4 is shown such a mechanical-acoustic oscillatory system consisting of two masses with a longitudinally strained rod between them. In this form, it has been possible to make such systems which even for frequencies of more than 1,000 cycles per second had for practical purposes separated mass and elasticity.

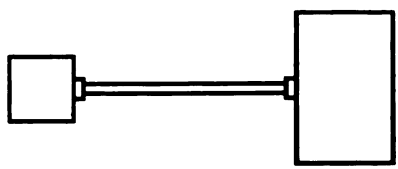

FIGURE 4

The coupling of such oscillatory systems to each other can be most readily carried out by supplying a mass which is common to each of them. In Figure 5 are illustrated schematically two such coupled systems. Herein a and b are the masses of one system; f the connecting elastic element; c and b the masses of the other system; and f the elastic element connecting them. The mass which is common to both systems, or the coupling mass, is b. The magnitude of the coupling mass, as compared to that of the other two masses, determines the coupling coefficient.

The expression

$$\frac{a\,c}{(a+b)\,(c+b)}$$

gives the product of the ratios of the oscillation energy present in the coupling member to the total energy present in each of the

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systems, and is called k^2. If the common mass b is small compared to each of the free masses a and c, practically all the oscillating energy is concentrated in the coupling element and we have the case of a strictly closed coupling or k^2 is equal to unity. If, on the other hand, b becomes larger than a and c, the coupling becomes more loose, and we have approximately

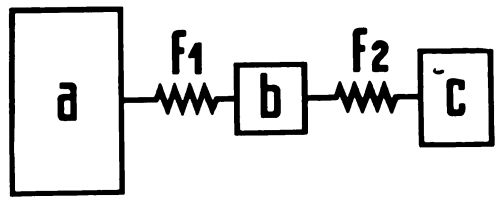

FIGURE 5

$$k^2 = \frac{a\,c}{b^2}.$$

We see here clearly the analogue to the coupling coefficient of two electrical circuits with their common inductance, which is well known to be

$$k^2 = \frac{M^2}{L_1 L_2},$$

where L_1 and L_2 are the free inductances, and M the common or mutual inductance. As a and c become small compared to the coupling mass b, we reach the case of extremely loose coupling, and k^2 approaches zero. Numerous experiments verified these formulas thru the widest range of conditions. It should also be mentioned that the consideration of these mechanical oscillatory systems not only gives us a simple picture of the production of the two oscillation frequencies caused by coupling, but also enables us mentally to follow without difficulty the oscillation phases of the separate masses. This coupled oscillation system is particularly suited for the examination of all the phenomena which occur because of coupling, and is particularly convenient for those who find it difficult to think along purely electrical lines.

In studying and investigating the more or less complicated electrical oscillatory systems, it is customary to subdivide them into separate closed electrical circuits which are coupled to each other in some fashion. In exactly the same way it is possible to study the design of complicated acoustic oscillatory systems by using closed mechanical-acoustic oscillatory systems

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as the basic form. It became possible only thru this means to get a clear idea of the oscillatory phenomena in sound signaling apparatus.

In addition to the closed systems, we have open or radiating systems, which are known as antennas in radio telegraphy. In acoustics, a radiating system is one which has surfaces that move into and out of the medium periodically. The simplest example of such an acoustic radiating system is the pulsating or "breathing" sphere. The laws of radiation for such a system were worked out by Lord Rayleigh. In practice, however, the vibrating diafram is of principal importance. We have succeeded, using Rayleigh's work as a basis, in calculating the radiation damping and equivalent oscillating mass of radiating systems and in particular for diaframs, just as this is possible for antennas in radio telegraphy.

For the pulsating or "breathing" sphere, it is found that the oscillating mass of the medium is

$$M = 4\pi R^3 \rho \frac{1}{1+\left(\frac{2\pi R}{\lambda}\right)^2}$$

where R is the radius of the sphere, ρ is the density of the medium, and λ is the wave length corresponding to the frequency in question. It can be seen from this that, in the practical and common cases, in which the radiator is small compared to the wave length, the associated oscillating mass of the medium is independent of the frequency, and approximately

$$M_{R \ll \lambda} = 4\pi R^3 \rho.$$

The radiation damping (logarithmic decrement) of the pulsating sphere is given by

$$\delta = 2\pi^2 \frac{R}{\lambda}.$$

It is assumed herein that the sphere itself is without mass; if it possesses a mass m, at its outer radius, it is found that

$$\delta = 2\pi^2 \frac{R}{\lambda} \cdot \frac{M}{M+m}$$

For the diafram, we have

$$M_{R \ll \lambda} = 0.4\, R^3 \rho \text{ and } \delta = 5 \frac{R}{\lambda} \cdot \frac{M}{M+m},$$

where R is the radius of the diafram, M is the associated oscillating mass of the medium, and m is the mass of the diafram itself, all of these being referred to the amplitude of the center

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of the diafram. These last formulas have been well substantiated by numerous measurements and experiments on diaframs.

In Figure 6 there is illustrated a cylindrical body which is closed on one side by a diafram. This is the simplified form of a radiating system for submarine signal engineering. We imagine this body to be surrounded by water, and its interior to contain air and the necessary exciting apparatus. The effect of this radiating system on the medium is due to the inward and outward vibrations of the diafram, whereby the medium is alternately subject to compression and rarefaction, and is moved to and fro. In the diafram, mass and elasticity are distributed

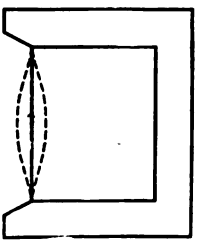

FIGURE 6

over the surface in some fashion, quite as in the case of inductance and capacity distributed over an antenna. Just as we carry out our calculations for the operation of coupled systems containing an antenna by reducing the antenna to an oscillating circuit with equivalent capacity and inductance, we have learned also to reduce this diafram system to an equivalent closed mechanical-acoustic oscillating system. For this purpose, we refer the mass of the diafram and the associated vibrating water mass of the free medium to the middle point of the diafram. The elasticity is referred to the same point, and thus we obtain the arrangement shown in Figure 7. Herein *b* is the sum of the masses supposedly concentrated at the middle point of the diafram, *a* is the mass of the housing or container, and *f f* is the elastic restoring force of the diafram also referred to its middle point. We see that we again have two masses in this case, which are connected to each other thru an elastic element. So that we have succeeded in reducing the diafram radiating system to the equivalent of a closed oscillating system. Thus we are able, for any desired acoustic apparatus, to produce the correct circuit diagram by successively representing each of the vibrating systems by the method given.

In Figure 8 there is shown a microphone such as is widely

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used as a receiver in submarine signaling. It consists of two electrodes between which powdered carbon is placed. The right hand electrode is fastened to the housing of the microphone and the left hand electrode to the microphone diafram. On the latter

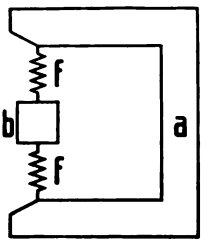

FIGURE 7

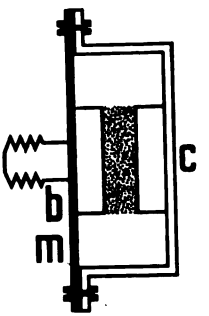

FIGURE 8

electrode there is also an arrangement for connecting to the middle point of the diafram. The microphone is a closed vibrating system. The two masses are those of the mass *c* and the mass *b*, and the elasticity is that of the microphone membrane *m*. A practical form of submarine signaling receiver is illustrated in Figure 9. There can be seen the housing of the receiver which is closed at one end by a diafram. The previously described microphone is fastened internally to the center of the diafram. The current is conducted to the microphone electrodes thru two flexible wires which lead to a cable passing thru a waterproof inlet into the housing of the receiver. The housing is, of course, surrounded by water, and contains air. The whole system consists of two coupled oscillation systems. The free mass of one portion is that of the receiver housing, and the other free mass is that of the housing of the microphone and the electrodes fastened to it. The common coupling mass of the

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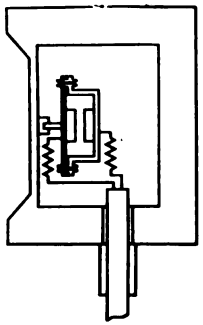

FIGURE 9

two oscillating systems consists of a number of connected parts and includes the other microphone electrode, the mass of the attachment element of the microphone at the diafram, the oscillating mass of the diafram referred to its center, and the associated oscillating mass of water also referred to this central point. From the magnitude of the two free masses and of the common coupling mass which is connected to them, the coupling coefficient of the two vibrating systems can be calculated according to the previous formula. This gives one of the important characteristics of the two oscillating systems.

In the case of submarine transmitters we are similarly concerned largely with coupled oscillating systems.

This will be illustrated by a description of the electromagnetic transmitter which was developed in the laboratory of the Signal-Gesellschaft at Kiel. In Figure 10 we have a schematic diagram of a construction thereof, in which *g* is the housing of the trans-

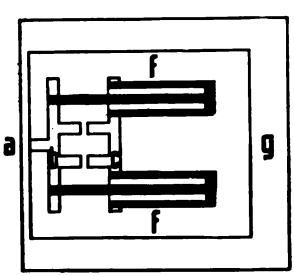

FIGURE 10

mitter and *a* is the diafram which shuts the housing *g* at one side. The oscillation energy is produced by excitation of the magnetic parts *b* and *c* by means of coils which are not shown. The masses *b* and *c* are connected by means of the elastic elements *f f*.

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Each of these elements consists of a cylindrical rod and a tube, of equal cross-section. Their function is to bring together parts *b* and *c*, and yet to obtain for the longitudinally strained rods or tubes a length given by the desired oscillation amplitudes. We are dealing here with two vibrating systems which are coupled by a common mass and each of which has its own free mass. One vibrating system consists of the diafram *a* in the housing *g*; the other vibrating system consists of both magnetic portions *b* and *c* connected by the elastic elements *f f*. The free masses are *c* and *g*. The common mass consists again of different portions, and includes the magnetic portion *b*, the diafram mass referred to its center, and the associated oscillating mass of water also referred to the center of the diafram.

In Figure 11 is shown a schematic "circuit diagram" of this arrangement. Both free masses are given by the mass *c* and the mass of the housing *g* (which is drawn as a ring). The common mass is indicated as *b*. The two elastic elements are represented by the springs *f f* and *e e*.

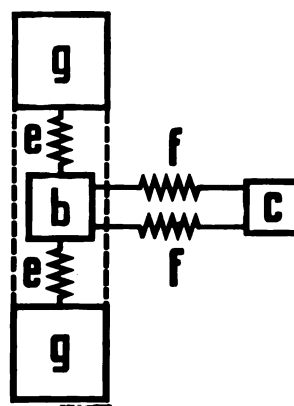

FIGURE 11

As will be seen, we are dealing here with two oscillating systems, one of which consists of the masses *b* and *c* and the spring *f f*, the other of the masses *g* and *b* and the spring *e e*. The coupling coefficient is again determined by the relation between the common mass and the two others. To obtain the best coupling coefficient and other desired results it is also necessary to tune the separate systems and to have suitable damping in each of them in relation to the coupling employed, just as is usually done in radio telegraphy.

In conclusion there will be shown a number of illustrations

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which will give typical examples of the employment of the submarine signaling transmitters which have been described.

In Figure 12, a transmitter in its actual form is shown. At the left is visible the transmitter which consists of two portions, between which the coils for exciting the transmitter are placed. This transmitter can be excited either with direct and alternating currents (polarized transmitter) or with alternating current alone

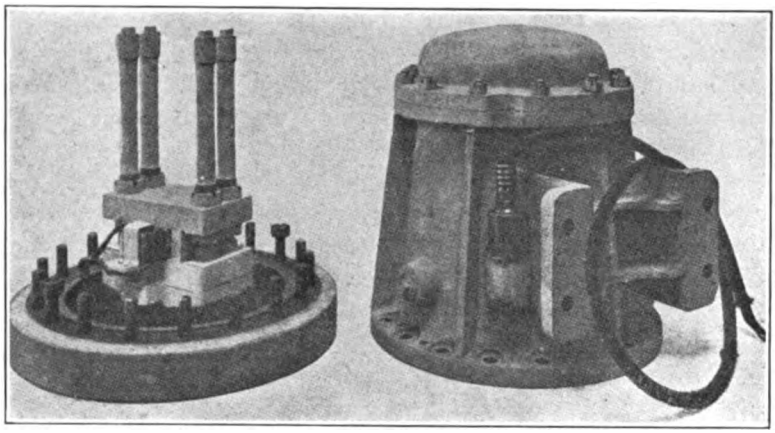

FIGURE 12

(unpolarized trsnamitter). In the former case, the acoustic and electric frequencies are the same: whereas in the latter case the acoustic frequency is twice the electric frequency. It may be mentioned briefly that the unpolarized transmitter is especially desirable in cases where a long cable is necessary for transmitting energy since there are then only needed two conductors in the cable, and in the case of ground return only one conductor.

Both magnetic portions are connected thru an elastic tube and rod system which consists of four such elastic members. The entire apparatus is screwed to a diafram, the outer rim of which is provided with fastening screws. By means of these screws the diafram can be fastened to the housing shown at the right. An electric cable is led into the housing thru a water-tight opening, and an alternating current from a generator, or the necessary direct current for polarization in addition (in the case of polarized transmitter) is sent thru the cable.

In Figure 13 such a transmitter is shown attached to a tripod which is suitable for location on the sea bottom in the open ocean. The cable passes from the transmitter down one leg of the tripod and then over the sea bottom to a land point.

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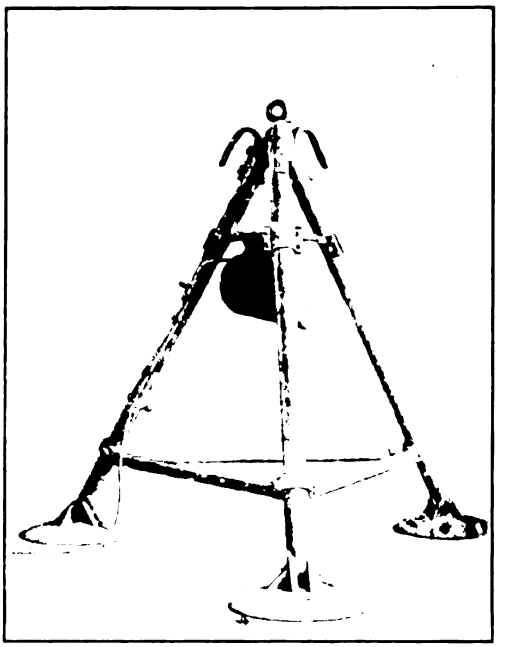

FIGURE 13

An entire installation of this sort is illustrated in Figure 14. The tripod stands on the sea bottom and the cable runs from it to the power station on land which is assumed to be located in in the neighborhood of a lighthouse. The transmitter sends sound waves out in all directions. Consequently all ships passing this point are able to receive the signals of the sound transmitter. They can even steer their course in accordance with these signals, as is nowadays done in foggy weather by utilizing the signals from submarine bells on lightships.

The first installation of this type was installed on the island of Rügen, near the German harbor of Sassnitz, several years ago. The railway ferry to Trellborg, a Swedish harbor, leaves this point. The transmitter is placed close to the lightship "Jasmund" and is intended to replace the latter.

The power installation of this transmitter is given in Figure 15 which, at Rügen, is located in the machinery room of a lighthouse. In the background can be seen the switchboard, and in the foreground the converter. In this case, 50 cycle polyphase power was available. This is first transformed into direct current. A motor generator then produces the 1,000 cycle single

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phase alternating current. The direct current is also used for polarizing the transmitter and for operating various pieces of auxiliary apparatus.

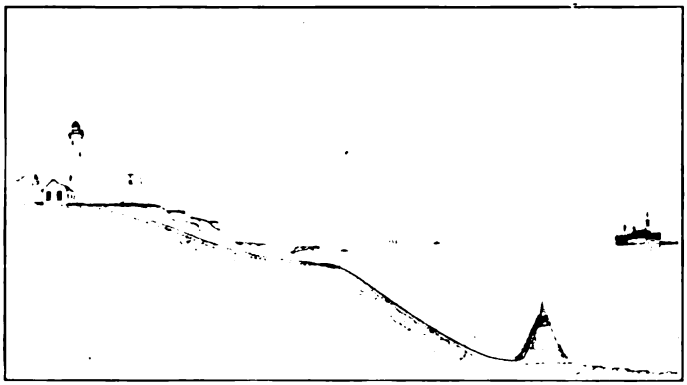

FIGURE 14

FIGURE 15

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The laying of the cable is shown in Figure 16, and illustrates the beginning of the process at the land end. In the background are seen the well known chalk cliffs of the island of Rügen. Figure 17 shows the laying of the cable in the ocean, Figure 18 the cable reel during the laying process, while Figure 19 shows the transmitter on its tripod during attachment of the cable and shortly before its submersion and setting up on the sea bottom.

FIGURE 16

FIGURE 17

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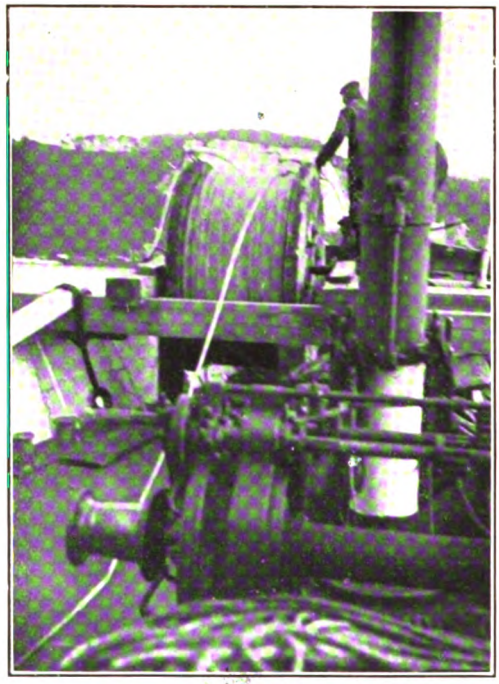

FIGURE 18

FIGURE 19

All the various sorts of submarine signaling apparatus are by no means covered by these two examples. There are several

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other forms of such apparatus which differ more or less from those described. But they almost always involve mechanical-acoustic oscillations which are produced or absorbed by means of oscillating systems. It is therefore desirable in the design and improvement of all such apparatus to proceed from the fundamental principles given above and to use the suitable "circuit diagrams" for determination of the oscillation engineering design of such apparatus.

The problems which have to be solved in submarine signal engineering are numerous, and to a large extent their field of application is similar to that of radio telegraphy. In some cases their applications are identical, as for example, in the methods of determining distance which depend upon the simultaneous reception of radio telegraphic signals and submarine signals from a certain point, such signals being sent, for example, from a lightship. There are other important cases where these two methods of signaling powerfully supplement each other, and their reciprocal contributions are therefore not only to be expected in the field of theoretical and experimental investigations, but also in the direction of practical application. I therefore hope that the material given here has been of interest to radio engineers.

SUMMARY: The acoustic systems corresponding to closed oscillatory electric circuits, to radiating electric systems, and to coupled circuits, are described. The design of submarine signaling transmitters and receivers on an engineering basis is described, and actual installations are discussed.

The resemblance of submarine signaling engineering and radio engineering, and the relation between these fields are considered.

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NOTE ON THE MEASUREMENT OF RADIO SIGNALS*

By

C. R. Englund

(Engineering Department, Western Electric Company, New York)

In 1917 (Proceedings of The Institute of Radio Engineers, volume 5, page 248, 1917) the writer advocated the method of measuring radio signals where a measured local input is compared with the signal to be measured. Such measurements have since been made in several quarters, but it is only recently that the writer himself has had the opportunity of working out the details for a successful measurement. In the following brief discussion this particular method and results are described.

Introduction

It is doubtful if any direct method of measuring radio signals of present-day intensities can be devised, the more so as with the increasing number of stations, a highly selective receiving apparatus is necessary for selecting the desired radiation. This leaves the indirect method of which the two variations are, a calibrated receiving set, and a local generator comparison, respectively. These two variations differ only slightly since the calibration of a receiving set requires the construction of a generator capable of delivering a minute measured input and the construction of such a generator automatically allows of the calibration of receiving sets. This calibration has been found readily possible, but at present the local comparison method appears the better for routine work, leaving the particular type and adjustment of the receiving set arbitrary.

Three means of identifying signal equality have been used in this laboratory, namely, the telephone receiver, the Braun tube, and a direct current meter. The former is usually, in telephone work, considered good for an accuracy of $\pm$ 1 mile of standard cable or approximately $\pm$ 12 percent. For radio work, with static present, this comparison is less accurately made. The telephone is particularly applicable to measurements during

*Received by the Editor, September 18, 1922.

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regular operation using as comparison source a local generator with its output broken up by a key as with the ordinary "omnigraph." The accuracies obtainable by a meter are limited only by the errors in reading the scale when static is absent, but fall off rapidly as static increases. A meter can only be used by pre-arrangement with the sending station, in telegraphic transmissions, as the sending key must be held down several seconds, but is immediately applicable for radio telephone measurements where the antenna current remains unbroken.

The accuracies obtained by the Braun tube have not been fully determined. Under moderate static conditions it excels the telephone on telegraphic signal measurements, but it becomes useless with excessive static. In practice the beam of electrons is deviated by a local alternating current source so as to give a bright line on the target and the incoming signals used to sweep this line at right angles to itself. The edges of the resulting rectangle are then easily defined thru moderate static.

Comparison methods may be listed as:

(a) Primary—where a local emf. is induced in the receiving antenna equal to the total emf. induced in this antenna by the signal to be measured; and,

(b) Secondary—where an emf. drop across an impedance favorably located in the antenna and associated circuits, and due to the resulting signal currents, is compared with the locally generated emf. In the first case, a knowledge of the antenna constants is unnecessary (except for such geometrical data as will allow a calculation of the ether electric field from the induced voltage resulting) and static is always present as it must be for telephonic comparisons. It is however more difficult to generate and control, at exactly the signal frequency, the smaller emf. thus needed. In the second case much larger and more easily measured inputs (not necessarily of signal frequency) may be used, but the antenna system must be carefully measured as a knowledge of its circuit constants is required. In either case the only requirement for the rest of the receiving set is that it be able successfully to select and amplify the desired signal.

For telephonic comparison it is necessary to switch rapidly from one input emf. to the other, and this can only be done for case (a), by using a rotating directive antenna (loop), or a pair of similar ones at right angles, unless by pre-arrangement the signals are regularly "on" and "off." At times the directivity of the static will give different interfering inputs on crossed directive antennas. For case (b) the local input can, if desired, be

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of a different frequency if applied directly to the detecting element. This is very easily obtained by beat reception, as for example by adjusting the beating oscillator frequency so that by adding a key and fixed reactance to this oscillator, the operation of the key will alternately "zero beat" the signal and local generator frequencies.

Experimental Work

This particular work was begun in October, 1921, at Cliffwood, New Jersey, and for several reasons Nauen, Germany (POZ), was chosen as the original signal source. While theoretically the receiving set used is immaterial, practically this was not found to be the case, since other interfering radiations differed too little in frequency from that of Nauen. The following table of stations and their nominal frequencies illustrates this.

Marion	WSO	26,100 cycles
Stavanger	LCM	25,000 cycles
Nauen	POZ Number 1	23,800 cycles
Bolinas	KET	22,470 cycles
New Brunswick	WII	22,050 cycles
Carnarvon	MUU	21,130 cycles

The worst interference came of course from Marion and New Brunswick. The primary requirement of the final measuring system was that it must be reasonably simple and portable, and this made a portable loop antenna necessary. Attempts were first made to obtain such a good loop zero on New Brunswick (distant about 11 miles or 17.6 km.) that this station would be eliminated, after which Marion could be sufficiently reduced by tuning so as not to interfere at the high pitched beat note resulting. This balancing out of New Brunswick was successfully accomplished out of doors, but in the laboratory the outside telephone line and the conduits for the power and lighting supply made a zero balance impossible. Accordingly a decided sharpening of the selectivity of the receiving set was made and the shielding of the set very carefully carried out. The resulting apparatus is shown in the wiring diagram of Figure 1 and gave excellent results. No other station but the desired one is heard during the measurements. A frequency-output curve for the set from loop to meter is given in Figure 2. The width of this resonance curve can be altered at will by adjusting the coupling condensers (4) of Figure 1, and the resonance frequency by varying condensers (5). With the constants given, an ether

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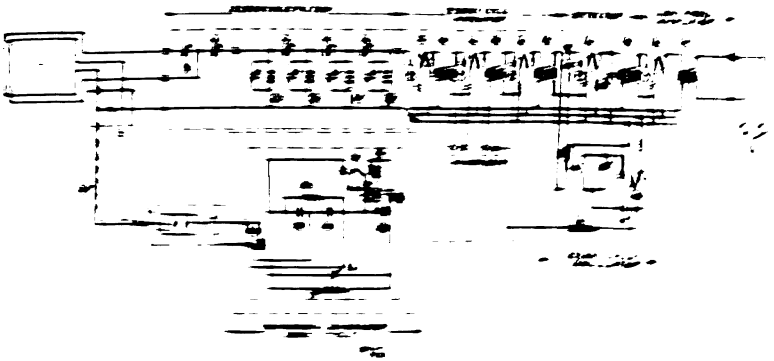

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little stray magnetic field and the electrostatic field is very easily shielded out.

The attenuation box is a carefully constructed artificial line of pure resistances and gives key settings of 1, 2, 3, 4, 10, 20, 30, and 40 miles of standard cable and combinations of these. Its surge impedance is 600 ohms and its construction shown in Figure 3.

$$\left[\frac{I_o}{I_{(N\ miles)}} = 10^{\frac{(N\ miles)}{21.12}}\right]$$

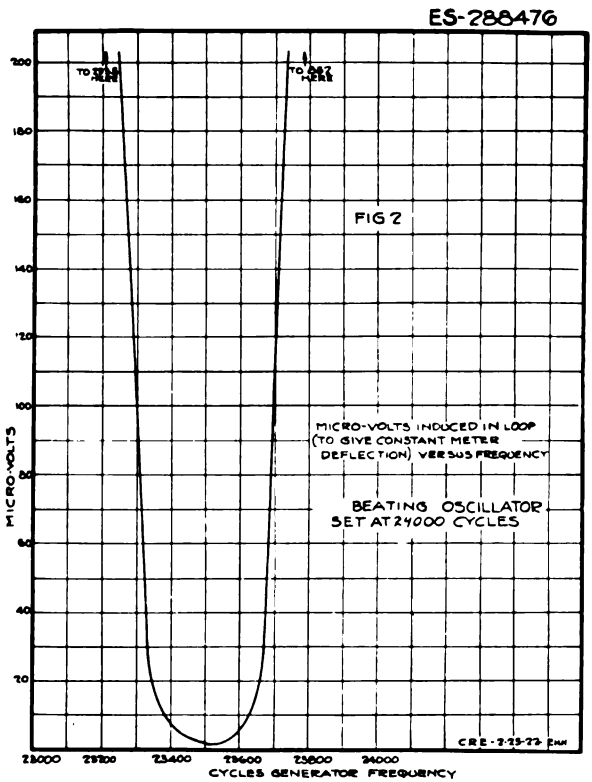

FIGURE 2

It gives very satisfactory results at the moderate radio frequencies used here, the key combinations checking against each other, and input and output current ratios being correct to the degree of accuracy with which meters can be read.

From the attenuation box the current is carried thru a copper tube to a copper terminal box on the loop base, and the drop

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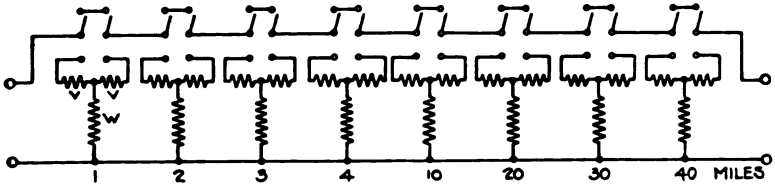
across a non-reactive 1 ohm resistance inserted in the loop. The conductor in the tube can be short circuited in the terminal box, and after removing the loop connections three milliamperes sent thru the tube without giving an audible response in the set. The total capacity between the central connector and the tube is about 200 micro-microfarads. With the heavy central con-



MILES	INPUT / OUTPUT	V	W
1	1.115	52.64	3500.5
2	1.244	65.13	2775.9
3	1.387	97.25	1802.2
4	1.547	128.77	1353.4
10	2.975	298.11	484.75
20	8.851	476.17	137.35
30	26.33	556.1	45.64
40	78.331	584.9	15.32

FIGURE 3

ductor used, the series resistance and inductance are so small that with a terminal impedance of 1 ohm the current attenuation thru the tube is, by calculation, considerably less than 0.1 percent. Three sources of error may be encountered. They are, in order of importance, inaccuracy in making the comparison, the distortion of the ether field by adjacent conductors, and the off-balance to ground of the loop. It is also probable that the use of too high attenuations in the attenuation box is risky, but this source of error can only be exposed by an independent method of accurately attenuating a small current to values unmeasurably directly. It has been found possible mostly to make aural comparisons to an accuracy of two miles of standard cable (24.4 percent.) and three miles (39 percent.) is never exceeded. Measurements on Nauen are never quite free of static, and so far a meter reading has not been possible. With the Braun tube, settings to better than 1 mile of standard cable are possible with moderate static.

The effect of adjacent conductors has so far only been noticed in connection with the local ungrounded wire telephone line, but it is probable that power circuits and conduit would show up in more accurate measurements. Incidentally a source of much

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Date 1922		Time	Frequency Approximate	Microvolts per Meter
Feb.	14	....	....	35
	16	11.15 A. M.	23,600	37
	16	3.45 P. M.	23,600	36
	17	10.00 A. M.	23,600	53
	18	10.00 A. M.	....	36
	20	10.00 A. M.	....	29 and 35
	21	10.00 A. M.	....	33
	23	P. M.	....	22
	24	9.35 A. M.	....	40
	25	P. M.	23,500	39
	27	P. M.	23,510	49
	28	A. M.	23,450	28
	28	3.15 P. M.	23,540	27
March	1	9.45 A. M.	23,400	50
	7	9.10 A. M.	23,540	44
	7	4.40 P. M.	23,600	..
	8	11.10 A. M.	23,540	48
	10	11.35 A. M.	23,500	49
	11	11.45 A. M.	23,560	44
	14	2.45 P. M.	23,640	43
	15	9.15 A. M.	23,590	49
	16	12.25 P. M.	23,460	49
	17	4.15 P. M.	23,480	35
	18	12.30 P. M.	23,440	61
	31	4.46 P. M.	23,466	38
April	1	9.05 A. M.	23,487	48
	3	4.30 P. M.	23,560	42
	4	11.35 A. M.	23,532	43
	5	1.45 P. M.	23,488	20
	8	11.05 A. M.	23,517	39
	10	2.10 P. M.	23,576	22

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trouble is due to the careless manner in which the electric power companies insulate their conductors, and on some days of strong wind and rain the New Jersey coast region becomes an extended source of severe interference to every receiving station having outside power or telephone connections.

The circuit shown in Figure 1 does not allow of a balancing of the loop to ground, but the unbalance effect has been shown to be negligible.

The apparatus described was, as stated, designed to measure Nauen's radiation and possesses enough flexibility to follow the rather marked variations in Nauen's frequency, but cannot cover any extended frequency range. For these, other condenser-coil combinations will be necessary, a change now being made.

The method of manipulation is as follows: a reading on a vacuum tube voltmeter or Braun tube connected to the output of the set is obtained with the loop end-on into the radiation and the same deflection duplicated by the local generator with loop broadside to the radiation. Or the vacuum tube voltmeter is replaced by a telephone and the two inputs alternately compared by turning loop and throwing the local generator on, the latter meanwhile, being broken up into signals if necessary as with Nauen. The voltage induced in loop is given by

$$V = \frac{2\pi f A N E}{3 \times 10^{10}}$$

where

f = frequency
A = loop area in cm.^{2}
N = number of turns
E = ether electrical field $\left(\frac{\text{volts}}{\text{cm.}}\right)$

A table of some observations on Nauen is attached. These are "key down" or peak field measurements.

SUMMARY: A portable compact measuring unit for incoming signal strengths has been worked out, capable of measuring from 3.5 microvolts per meter up, at 23,500 cycles, and giving satisfactory results. The measurements are made by a primary comparison with a locally generated emf. by means of a highly selective receiving unit and a 600-ohm artificial line box especially made for this purpose. The method is equally applicable to other frequency ranges and should be especially convenient at the higher radio frequencies where the absence of static allows of meter comparisons and the use of the double detection method of reception. This latter method allows of a fixed filter adjustment for all frequencies and is very flexible.

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RELATIONS OF CARRIER AND SIDE-BANDS IN RADIO TRANSMISSION*

By

R. V. L. Hartley

(Western Electric Company, Incorporated, New York)

As indicated by the title, this paper will discuss some of the phenomena associated with radio transmission in terms of the carrier currents and side-bands into which a modulated wave may be resolved. The use of these terms implies a point of view which perhaps is employed less commonly in radio engineering than in some of the other branches of the communication art. For this reason, I shall, at the risk of repeating much that is already in the literature,[1] review such of the fundamentals of this viewpoint as are necessary to an understanding of what is to follow.

Analysis of a Signal Wave

Briefly stated, the point of view is that any signaling wave may be resolved into sustained sinusoidal components, which may be thought of as traversing the system as individual currents and recombining at the receiving end to form the reproduced signal. The possibility of such a resolution has been demonstrated mathematically and the formulas for evaluating the amplitudes and phases of the components are well known. A periodic wave may be expressed as a Fourier series, that is, as the sum of an infinite series of components the frequencies of which may be thought of as harmonics of a fundamental frequency which is equal to the frequency of repetition of the wave. Such a resolution, however, is not directly applicable to the waves employed in communication, for by their very nature they are not periodic. A communication system must be capable of transmitting any individual symbol regardless of what precedes or follows it. We

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[1] "Carrier Current Telephony and Telegraphy," by E. H. Colpitts and O. B. Blackwell; "Transactions of the American Institute of Electrical Engineers," volume XL, page 205, 1921. "Application to Radio of Wire Transmission Engineering," by L. Espenschied; presented before The Institute of Radio Engineers, January 23, 1922.

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may, however, resolve such an aperiodic wave by the mathematical device of assuming it to be one cycle of a periodic wave in which the interval between successive occurrences of the disturbance in question approaches infinity. The frequency of repetition is then infinitesimal. The fundamental frequency of the Fourier series and the frequency interval between adjacent components are also infinitesimal; that is, the series of discrete lines of the Fourier series spectrum merge into a continuous spectrum. Mathematically this continuous spectrum is represented by the expression

$$F(t) = \int_0^\infty S \cos(qt + \Theta)\, dq, \qquad (1)$$

which is known as the Fourier integral. Physically we are to picture this infinite series of sustained sinusoids as having such amplitudes and phases that the algebraic sum of their instantaneous values is zero for all instants before and after the disturbance in question, and equal to the instantaneous value of the wave thruout its duration. In Figure 1, curve A represents a telegraph dot, curve B gives the relative amplitudes, S, of its components plotted against their frequencies, and curve C, their phase, Θ, also as a function of frequency. The so-called "dot frequency" corresponding to a sustained succession of such dots is indicated on curve B.

It is obvious that if either the amplitudes or the phases of the components be distorted, their instantaneous sum will be changed; that is, the wave resulting from their re-combination will be a distorted reproduction of the original wave. Also, those parts of the frequency range in which the amplitude is negligibly small can contribute little to the reproduced wave, and the elimination of all components in those ranges will have little effect on the quality of reproduction. Just what ranges it is essential to retain depends upon the nature of the signal and the standard of reproduction that is set up. What is important for present purposes is the fact that the faithfulness with which a system will reproduce any arbitrary signal disturbance is deducible, in theory at least, from a knowledge of its transmission of sustained single frequencies. By this is meant a knowledge of how the relation, both in amplitude and phase, between the input and output sinusoidal wave varies as the frequency of the wave is progressively varied thruout the frequency range.

Analysis of a Modulated Wave

Let us assume now that a radio system is called on to transmit such a signal wave, $F(t)$, which may be either a telephone

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or a telegraph signal. If, as is commonly assumed, the modulator causes the amplitude of the carrier wave, $C \cos pt$, to be varied in accordance with the signal, the resulting modulated wave may be expressed as

$$m = C\,[1 + k\,F\,(t)]\,\cos pt, \qquad (2)$$

where k is a factor which measures the so-called degree of modulation. If the largest negative value of $k\,F(t)$ is just equal to

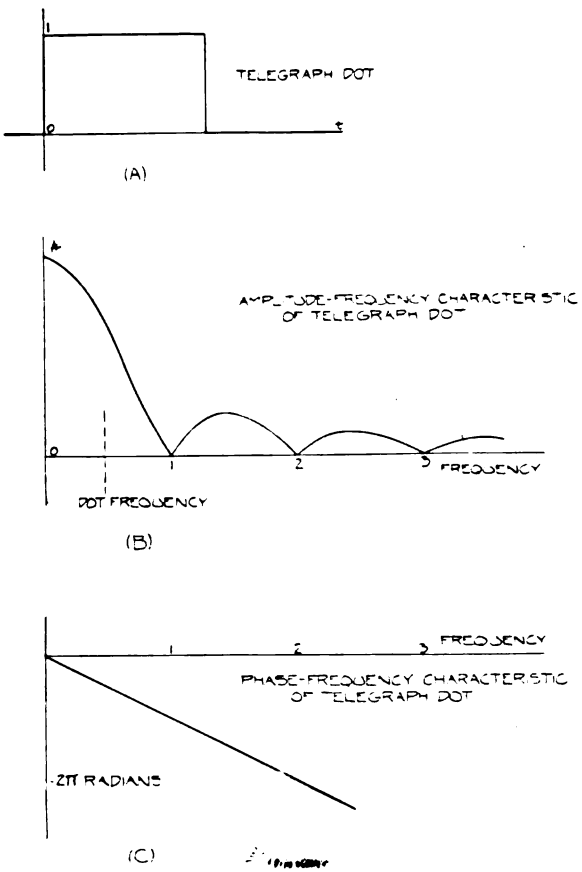

FIGURE 1

unity, so that the instantaneous amplitude of the carrier wave just falls to zero, the modulation is said to be complete. The significance of complete modulation will be discussed later.

Now let us resolve the signal wave into its infinite series of components, each of the form $S \cos (qt + \Theta)$, where S and Θ vary

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with the frequency $\frac{q}{2\pi}$. Neglecting non-essential frequencies, q may be considered to cover a range from q_1 to q_2. If this value of $F(t)$ be substituted in (2) we get

$$m = C \cos pt + k\,C \cos pt \int_{q_1}^{q_2} S \cos (qt+\Theta)\, dq. \qquad (3)$$

The first term, which is independent of the signal, represents a component having the carrier frequency, $\frac{p}{2\pi}$. The second term represents an infinite series of terms each derived from only one component of the signal. Hence each component of the signal is represented in the modulated wave by an expression of the form,

$$k\,C\,S \cos (qt+\Theta) \cos pt = \frac{1}{2} k\,C\,S\,[\cos[(p+q)t+\Theta] + \cos[(p-q)t-\Theta]. \qquad (4)$$

This represents two sinusoidal components, the frequencies of which differ from that of the carrier by the frequency of the particular signal component. The similar expressions for the other signal components each yield a pair of components similarly placed with reference to the carrier. All of these taken together form a pair of spectra or frequency bands extending on either side from the carrier frequency in the same way that the spectrum of the signal extends from zero frequency. These bands of frequencies are spoken of as "side-bands" and the component currents of these frequencies as "side-band currents," or, more often, simply as "side-bands." The side-band which extends upward in frequency from the carrier is called the "upper side-band," and the other, which extends downward, the "lower side-band."

The form of these side-bands is shown schematically in Figure 2, where purely arbitrary curves are used to represent the amplitudes and phases of the signal components over a limited frequency range. It will be seen that the corresponding curves for the upper side-band are derived from these by displacing them along the frequency axis by the amount of the carrier frequency. The amplitude curve of the lower side-band is derived by inverting that of the upper with respect to the carrier frequency. For the phase curve of the lower side-band that of the upper is to be similarly inverted and also reversed in sign. The actual magnitude of the side-band currents relative to the carrier depends on the degree of modulation, k, of equation (2). For com-

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mercial telephony the limits of the essential band may be taken roughly as 200 and 2,000 cycles. If high quality speech or music is to be transmitted, a wider band is required. For telegraphy the band width required varies widely with the speed of sending and the type of apparatus used. In general, it is desirable to preserve very low frequencies, which means that the two side-bands practically meet at the carrier frequency.

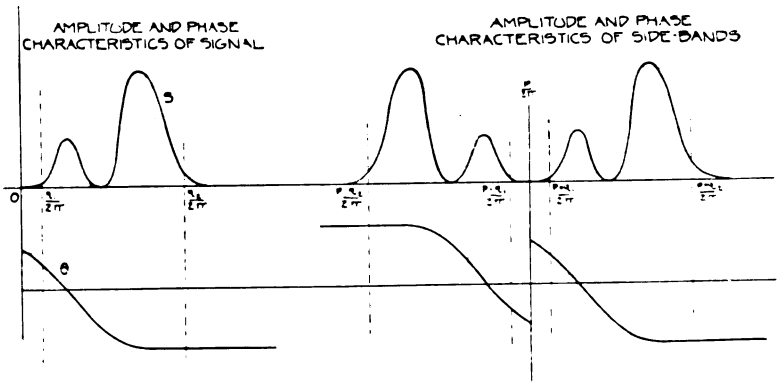

FIGURE 2

REPRODUCTION OF THE SIGNAL WAVE

Having arrived at a picture of the modulated wave as given by equation (4), we shall first discuss the reproduction of the signal from this as it stands, and then consider the effect on this reproduction of various modifications to which the modulated wave may be subjected before or during the process of detection. While any device in which the current voltage characteristic is non-linear may be used as a detector, the operation of the vacuum tube lends itself to analysis because of its approximation to a parabolic current voltage relation. That is, we may write,

$$i = a_0 + a_1 v + a_2 v^2, \tag{5}$$

where v is the voltage impressed on the grid, in this case the modulated wave, and i is the resulting current. As the first term is independent of v and the second represents simple amplification, detection[2] can result only from the third term, $a_2 v^2$. Since a_2 multiplies all components of v^2 alike, we may neglect it and simply consider the square of the expression for the modulated wave. This results in a series of terms which are the squares

[2] In practice this parabolic law seldom holds strictly, and secondary contributions are made to the detected wave by terms of higher power.

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of the individual components and another which are their products taken in pairs. Since

$$\cos^2 x = \frac{1}{2}(1+\cos 2x), \tag{6}$$

the square terms will yield only direct current, and currents of approximately twice the carrier frequency. The product terms, each of which contains the product of two cosines, may, as in the case of the modulated wave above, be transformed into the sum of two cosine terms the frequencies of which are respectively the sum and difference of the component frequencies. Of these only the difference frequencies can lie in the range of the original signal. In other words, we may think of the reproduced wave as made up of the sum of all the heterodyne beat notes resulting from all the pairs of component sinusoids of the modulated wave.

The carrier component, $C \cos pt$, beating with a component of the upper side-band, $\frac{1}{2} k C S \cos [(p+q)t+\Theta]$, equation (4), gives the beat note or reproduced component,

$$r_+ = \frac{1}{2} k C^2 S \cos (qt+\Theta), \tag{7}$$

which is identical in frequency and phase with the corresponding component of the signal, and has an amplitude proportional to that of the signal component. Exactly the same expression results from beating the carrier and the corresponding component of the lower side-band. These two low frequency components, being in phase, add directly to give

$$r = k C^2 S \cos (qt+\Theta) \tag{8}$$

as the reproduced component. As the factor $k C^2$ is independent of q, all of the signal components are reproduced with the same relative amplitudes and phases, as in the original signal. Their sum is therefore $k C^2 F(t)$, and the signal is accurately reproduced.

However, there are still other components of the modulated wave to be considered. Every pair of components in one side-band beat to give the difference of their frequencies, which is also the difference of the corresponding signal components. The corresponding pair of components of the other side-band yield an identical component and the two add in phase. Similarly every component of one side-band beats with every component of the other, giving in each case the sum of two component frequencies of the signal wave. Like the difference frequencies, each of these sum frequencies is produced twice. The combination of

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the components of the two side-bands which were derived from the same signal component yields a component of twice the frequency of the signal component. The addition of these extraneous components serves to distort the reproduced wave in a manner quite similar to that of external interference. It is of interest therefore to consider the magnitude of these distorting components relative to the reproduced signal. The product of two side-band components of amplitudes $\frac{1}{2} k C S$ and $\frac{1}{2} k C S'$, equation (4), gives as the amplitude of one of the two components of the difference frequency $\frac{q-q'}{2\pi}$, $\frac{1}{4} k^2 C^2 S S'$. Comparing this with the amplitude, $\frac{1}{2} k C^2 S$, equation (7), of one of the two reproduced signal components of frequency $\frac{q}{2\pi}$, the ratio of the undesired to desired component is found to be $\frac{1}{2} k S'$. It is evident that this type of distortion increases with the degree of modulation, k, or, as will be discussed more fully later, with the ratio of carrier to side-band.[3]

Single Side-Band Transmission

So far it has been assumed that the wave applied to the detector is identical with that produced by the modulator, a condition seldom encountered in practice. For, in addition to the undesired modifications which the modulated wave undergoes because the transmission characterictics of practical circuits are not ideal, there are other changes which when properly made yield distinct advantages. These intentional changes will be discussed first.

It will be remembered that any component of the signal can be reproduced by the combination of the carrier with either side-band. Hence it is unnecessary to transmit both side-bands. Suitably designed electrical filters make it possible to transmit one side-band and effectively suppress the other.[4] This makes possible a very great saving in the frequency range required per channel. It is of particular importance for long wave radio telephone transmission where the width of a single side-band is so large a fraction of the total frequency range available that the

[3] A similar form of distortion generally occurs in modulation, resulting in new components being produced in the frequency range of the side-band.

[4] For a description of such filters see the Colpitts and Blackwell paper referred to above.

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number of independent channels is at best very limited. The intensive development of a limited frequency range by the use of single side-band transmission has probably progressed farthest in connection with carrier telephony over wires. Here commercial service is being given over circuits on which the carrier currents of adjacent channels are separated by only 3,000 cycles. It is obvious that the transmission of both bands would nearly double this separation, thereby halving the number of channels per circuit. There is, of course, no reason why similar savings may not be effected in the field of radio transmission. In addition to this major advantage there is an incidental improvement in the quality of reproduction, for the distorted components resulting from beats between components of the two side-bands, that is, the sums of the signal frequencies, are eliminated.

Carrier Suppression and Homodyne Reception

The other important modification has to do with the so-called "unmodulated" component of carrier frequency, $C \cos p t$, in equation (3). As already pointed out, good signal reproduction requires that at the detector this shall not be too small relative to the side-bands. However, it is merely a continuous alternating current, and does not itself partake of the signal variations. It is therefore immaterial whether it is transmitted from the modulator or is supplied to the detector by a local source such as an oscillator. The elimination of this component from the modulated wave at the sending station is spoken of as "carrier suppression," and its re-introduction at the receiving end as "homodyne" or "zero beat" reception. The term homodyne implies supplying the same wave as distinguished from heterodyne, meaning another. Zero beat refers to the bringing of the local carrier into synchronism with the sending carrier by reducing the beat note between them to zero frequency. While homodyne reception is essential to carrier suppression, the reverse is not true. The reception of an ordinary modulated wave may sometimes be improved by the addition of carrier at the receiving end.

The primary advantage of carrier suppression lies in the saving of sending power which it makes possible, or, what is equivalent, the increase in range made possible when all the power of a given station is utilized in the side-band. Of the various ways in which this suppression may be accomplished, the simplest is by the use of a so-called balanced modulator as shown

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schematically in Figure 3. Carrier frequency from the source C is applied to the grids of two vacuum tubes in the same phase, while signal currents, indicated at S, are applied to the two in opposite phase. The two plate circuits are differentially connected with a common output citcuit. In the absence of signaling current the amplified carrier frequency currents from the two tubes neutralize each other and nothing is transmitted. With the application of signaling current one grid is raised in potential and the other lowered, with the result that more radio frequency is developed by the first tube than by the second and the excess appears at O. The magnitude of this radio frequency current is proportional to the instantaneous value of the signaling current. Upon reversal of the direction of the signaling current the effect of the second tube predominates and radio frequency is again transmitted, this time with the phase reversed, owing to the differential connection. The wave form of a signaling current and the resulting output current are roughly as shown in Figure 4, A and B. If this output be amplified for transmission there will be no load on the amplifier and antenna except during actual speech, when it will be proportional to the intensity of the speech.

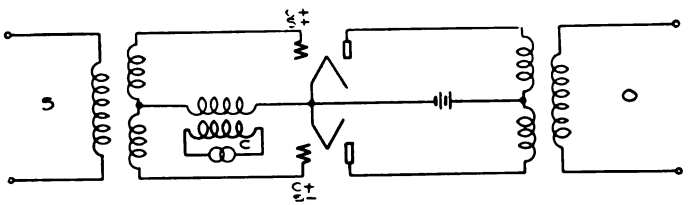

FIGURE 3—Balanced Modulator

That these intermittent pulses of carrier frequency produced by a balanced modulator are equivalent to a modulated wave from which the carrier frequency component has been removed, may be easily shown. Consider a single sinusoidal component $S \cos(q t+\Theta)$, of the signaling wave which is applied to the balanced modulator. The resulting output current is a wave of carrier frequency, the amplitude of which is proportional to C and to S and varies cyclically with a frequency $\frac{q}{2\pi}$ between the values $+K C S$ and $-K C S$, where K is a constant of proportionality and the negative amplitude indicates a reversal of phase during half of the audio frequency cycle. Such a variation may be represented by the expression

$$i = K C S \cos(q t+\Theta) \cos p t. \qquad (9)$$

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Taking the sum of these expressions for all the components of the signal gives the second term of Equation (3) which was shown to represent the side-bands.

In estimating the power saved by carrier suppression the comparison should be made with a system transmitting the carrier which has been so adjusted that the power is used to the best advantage. So far as a single signal component is concerned this would call for making the carrier and side-band equal, as their product would then be a maximum. This, however, would imply that the distorting currents from the interaction of two side-band components would be as large as the signal currents themselves. That is to say, quality considerations require that the major part of the transmitted power be in the carrier component. Quantitative data on the relation between the ratio of carrier to side-band and the quality of transmission has been secured in the laboratories of the Western Electric Company, and it is hoped it will be published in the near future. Briefly, the results indicate that the good quality which is obtained when the carrier component is large falls off very rapidly as the magnitude of the carrier component is reduced so as to approach that of the side-band, the latter being measured when a sustained "ah" sound is used as the signal. Under these conditions the side-band is sustained at a value about equal to the maximum occurring in ordinary speech. That is to say, even the peak power in a carrier suppression system is less than the carrier component alone in an ordinary system adjusted to give the same side-band. From these considerations it appears that there has been a tendency to attach undue significance to "complete modulation," as a more or less unique and ideal condition of operation. For nothing revolutionary occurs as the carrier is decreased thru the value corresponding to that condition. The distortion due to interaction between the side-bands is present for larger values of carrier and continues to increase progressively for smaller values. The exact degree of modulation to be permitted therefore depends upon the standard of quality to be met. In a carrier suppression system the degree of modulation, k, approaches infinity more or less closely depending on the completeness of the suppression.

In addition to making possible the use of carrier suppression, homodyne reception presents other advantages. It furnishes a ready means of increasing the intensity of the reproduced signal, since this is proportional to the carrier component at the receiver as well as to the side-band. Also, by making the carrier large,

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k is made very small and the distorting currents due to interaction of the side-bands become negligible. The use of a large local carrier in homodyne radio telephony assists in frequency selection in the same way as does the hetrodyne wave in radio telegraph reception. Suppose an interfering message is separated from the desired one by only a few thousand cycles and so is not entirely suppressed by the receiving selective circuits. Currents of voice frequency can be reproduced from its side-bands only by interaction with its own carrier, and hence they will be small compared with those of the desired message, which are proportional to the local carrier. On the other hand, the large currents due to the interfering message and local carrier will all have frequencies above the voice range, and so can be suppressed by selective circuits in the output of the detector.

The same general reasoning applies also to static interference. Appreciable interfering currents of signal frequency can result only from those components of the static wave which lie in the frequency range of the side-bands. Moreover, they will bear the same ratio to the signal currents as do the static components to the side-band components. We may conclude, then, that when means are provided for eliminating all of the static except that which is inherently inseparable from the signal, the disturbing effect of the residue is determined solely by the relative magnitude of the *side-band* components and the static components which lie in the same frequency range. As the object of high power stations is to make the signals large compared with the static, the importance of concentrating the power in the side-bands rather than in the carrier is obvious.

Effect of Radio Distortion

Let us pass now from the intentional modifications of a modulated wave and consider the effects of unintentional distortions. Limiting our attention first to systems in which the carrier is transmitted, we have to consider the effect of distortion such as might be introduced by the sending and receiving circuits and the transmitting medium. Assuming the characteristics of these to be known in terms of their transmission of sinusoidal components of various radio frequencies, we wish to determine their effect on the amplitudes and phases of the components of the reproduced wave. We shall assume the current voltage relations in the transmission system to be linear, so that no new frequencies are introduced. Then any possible distortion in the modulated wave may be represented by assigning the proper amplitudes and

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phases to all of the components. Corresponding to a single component of the signal we may write for the received wave

$$m = B\cos(pt-\phi)+B_+\cos[(p+q)t+\Theta-\phi_+]+ B_-\cos[(p-q)t-\Theta-\phi_-] \qquad (10)$$

where the amplitude, B, and phase lag, ϕ, may vary in any arbitrary manner for the different components of the modulated wave. We shall assume that B is always large enough compared with B_+ and B_- that the interaction between the side-band components may be neglected. It will be seen that the single frequency components reproduced from the two side-bands are not in general equal nor in phase and may either aid or tend to neutralize each other. They will be of the form,

$$B\Big[B_+\cos[qt+\Theta-(\phi_+-\phi)]+B_-\cos[qt+ \Theta-(\phi-\phi_-)]\Big]. \qquad (11)$$

Taking the resultant of these two gives as the component of the reproduced wave,

$$r = R\cos(qt+\Theta-\psi) \qquad (12)$$

where

$$R = B\sqrt{B^2_+ + B^2_- + 2B_+B_-\cos[(\phi_+-\phi)-(\phi-\phi_-)]} \qquad (13)$$

$$\tan\psi = \frac{B_+\sin(\phi_+-\phi)+B_-\sin(\phi-\phi_-)}{B_+\cos(\phi_+-\phi)+B_-\cos(\phi-\phi_-)}. \qquad (14)$$

It is evident that both the amplitude, R, and the phase shift, ψ, of the reproduced component depend upon both the amplitudes and phases of the corresponding components of both side-bands and on the phase of the carrier. The amplitude depends also on the amplitude B of the carrier, but as variations in this affect all components alike, they do not alter the wave form of the reproduced signal, but only its magnitude.

The expressions for the reproduced wave become much simpler for a system in which one side-band, say the lower, is suppressed. Then

$$B_- = 0 \qquad (15)$$

and equations (13) and (14) reduce to

$$R = BB_+ \qquad (16)$$

$$\psi = \phi_+ - \phi. \qquad (17)$$

The amplitude of the reproduced component is independent of

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the phases in the modulated wave, and is proportional to the amplitude of the side-band component. Hence amplitude distortion of the reproduced wave can result only from unequal transmission of the different component frequencies of the side-band. The change in the amplitude curve for the signal will be identical with that of the side-band. The phase shift, ψ, is independent of amplitude distortion of the modulated wave. It is equal to the difference between the phase lags of the side-band component and the carrier. Fortunately the quality of telephone reproduction is not seriously impaired by shifting the phases of the various components by even as much as several cycles. In telegraphy, however, the shape of the signal current which operates the relay depends very much on the preservation of the proper phase relations of the components, and the entire nature of the signal may be changed by phase shifts of even a fraction of a cycle.

It is worth while then to examine some of the phase shifts which are likely to occur in practice. Transmission of a sinusoidal wave thru the free ether involves a phase lag proportional to the distance and to the frequency. Hence the phase lags, ϕ_+ and ϕ, due to this cause, will be proportional to $p+q$ and p respectively, and their difference, ψ, will be proportional to q. Replacing ψ by $h\,q$ in equation (12) and regrouping terms gives

$$r = R\cos[q(t-h)+\Theta]. \qquad (18)$$

By displacing the origin of time by h this becomes identical with the original signal component. Also, since h is independent of q, the same time shift brings all the components into agreement; that is, a phase shift proportional to the frequency does not distort the wave, but merely delays it by the corresponding time of transmission.[5] In considering the terminal circuits then it is only the departure of their phase lag versus frequency curve from a straight line that need be considered as a source of distortion. It is of interest to note here that for most filters this relation is approximately linear thruout the range of free transmission. The actual curves for a particular band filter are shown in Figure 5, where there is plotted against frequency the relation of the amplitude and phase of the current at the third section of an infinite filter to those of the voltage applied to the first section. It will be noticed how the phase curve departs

[5] For a fuller discussion of this point see a paper by T. C. Fry on "Theorie des binauralen Hörens nebst einer Erklärung der empirischen Hornbostel-Wertheimerschen Konstanten," "Physikalische Zeitschrift," 23, page 273, 1922.

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abruptly from a straight line at the edges of the band where the sudden drop in the amplitude curve occurs. Similarly Figure 6 shows how in the current voltage relation of a simple resonant circuit, the distortion of phase and of amplitude occur together.

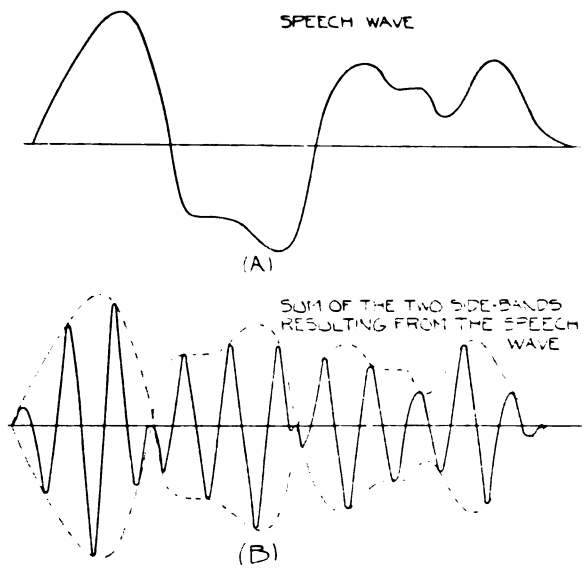

FIGURE 4

In case both side-bands are transmitted, a simple relation is found if the distortion is symmetrical with respect to the carrier frequency. By this is meant that, however the different components are distorted relative to each other, for every signal component the two corresponding side-band components are equal in amplitude and are shifted in phase relative to the carrier by the same amount; that is to say, for every value of q considered separately,

$$B_+ = B_- = B_* \tag{19}$$

$$\phi_+ - \phi = \phi - \phi_- = \partial. \tag{20}$$

Then

$$R = 2\,B\,B_* \tag{21}$$

$$\psi = \partial. \tag{22}$$

The same considerations as to distortion of the side-band apply here as for the single side-band. There is one point, however, of some practical significance. As is evident from Figure

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6, the characteristics of a resonant circuit come very close to satisfying these symmetrical conditions if the carrier coincides with its resonance frequency. Its effect on the amplitude and phase curves of the reproduced signal may therefore be derived independently from the amplitude and phase curves of the tuned

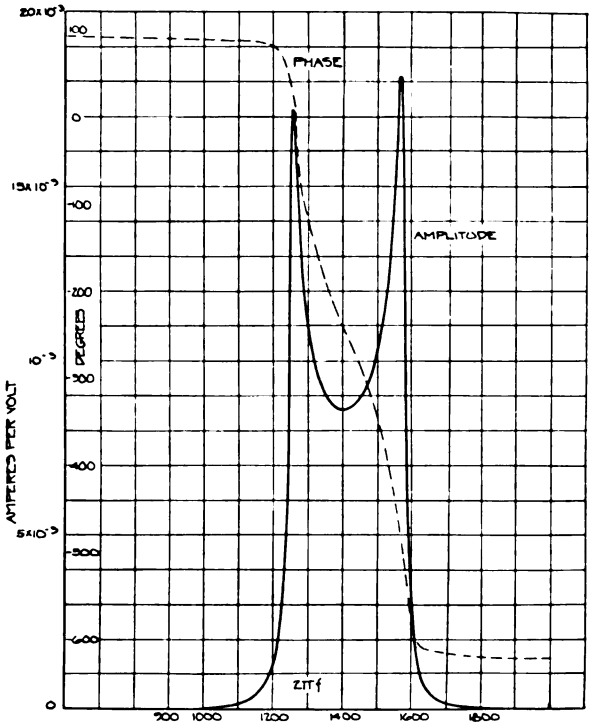

FIGURE 5—Amplitude-Frequency and Phase-Frequency Characteristics for Band-Pass Filter

circuit. If, however, the circuit be detuned, this symmetry is upset and we are forced to the complicated relations of equations (13) and (14), from which it is difficult to draw general conclusions.

An interesting case of unsymmetrical transmission is that in which one side-band is only partially suppressed owing to insufficient selectivity. Let us assume that the upper side-band is transmitted without distortion. Then for a given amplitude of the lower side-band its effect on the amplitude curve of the reproduced signal will be worst when the phase relations are such that for some frequencies it aids the upper side-band and for others it opposes. The greatest fractional change in the amplitude of

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any one signal component due to the presence of the lower side-band occurs when the two oppose. It is then reduced in the ratio

$$\frac{B_+ - B_-}{B_+} = 1 - \frac{B_-}{B_+}. \qquad (23)$$

Thus, if the lower side-band component were a tenth of the upper, the most it could do would be to change the amplitude of the

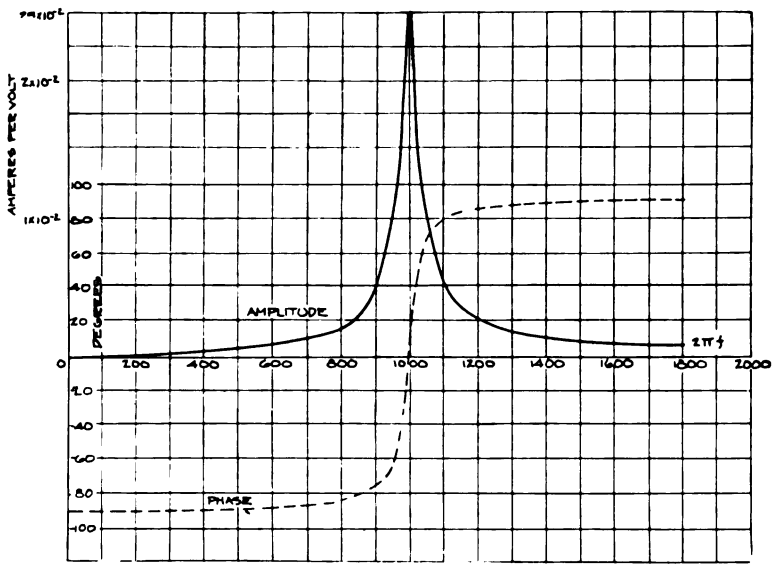

FIGURE 6—Amplitude-Frequency and Phase-Frequency Characteristics of Simple Resonant Circuit

signal component by a tenth. Such a change would have little effect on telephone quality, particularly as it would have this maximum value at only a few frequencies. The case of telegraphy is rather different. Here the two side-bands lie so close together that it is practically impossible to separate them by radio selective circuits, and even when, as in wire transmission, so low a carrier frequency is used that the two may be separated fairly well by filters, the side-bands corresponding to the lower signal components differ so little in frequency that even a sharp filter does not produce very great discrimination between them. This, coupled with the fact that the phase shift of a filter ceases to be linear near the edge of the transmitted band, leads to very considerable amplitude distortion.

The effect of the unsuppressed side-band on the phases of the

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reproduced components is also rather complicated. Equation (14) shows that it is a maximum when

$$\begin{aligned} \phi_+ - \phi &= 0 \\ \phi - \phi_- &= 90°, \end{aligned} \tag{24}$$

in which case the presence of the lower side-band changes $tan\ \psi$ from 0 to $\frac{B_-}{B_+}$. As in the case of amplitude, this effect is unimportant in telephony, but would need to be considered in telegraphy.

Phase of the Local Carrier

Coming now to homodyne reception, the important new factor to be considered is the fact that the carrier component is now perfectly arbitrary in amplitude and phase. This is true even tho the sending carrier is not suppressed, for, by suitably choosing the local carrier, the resultant of the two may be given any desired value. Since the amplitude of the carrier affects only the magnitude of the reproduced signal as a whole, we need consider here only the effect of arbitrary values of its phase, ϕ. For simplicity we shall assume that the modulated wave reaches the receiver unchanged except for the phase lags involved in undistorted transmission. Let us designate by ϕ_1 the phase lag of the carrier which is received from the transmitting station or would be received if it were not suppressed. Then

$$\phi = \phi_1 + \gamma, \tag{25}$$

where γ may be regarded as the phase displacement of the local carrier.

Consider first a system in which one side-band is suppressed. From equation (16), the amplitudes of the reproduced signal components are independent of the phase of the carrier. From equation (17), the phase,

$$\psi = \phi_+ - \phi_1 - \gamma. \tag{26}$$

But $\phi_+ - \phi_1$ represents only the phase shifts of undistorted transmission; that is, the delay suffered by the signal as a whole. Hence the net result is that all components have their phases shifted by the same amount; namely, the phase displacement of the carrier, which can never be more than a single cycle. For telephony this is of no practical importance, but it is evident that in a telegraph system using side-band suppression and homodyne reception the phase of the local carrier would have to be very carefully controlled.

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Consider now the case of homodyne reception of both side-bands received without distortion; that is,

$$B_+ = B_- = B_\pm \tag{27}$$

and

$$\phi_+ - \phi_1 = \phi_1 - \phi_- = h\,q. \tag{28}$$

From these relations and equations (13) and (14) we get

$$R = 2\,B\,B_\pm \cos\gamma. \tag{29}$$

$$\psi = h\,q. \tag{30}$$

This shows that the amplitude of every component varies as $\cos\gamma$; that is, when the local carrier is in phase or 180° out of phase with the received carrier the reproduced components are maximum for intermediate values they decrease, becoming zero when the two carriers are in phase quadrature. The phase lag, $k\,q$, is that due to transmission alone; that is, the phases of the reproduced components are independent of the phase of the local carrier. Since the phase of the local carrier affects only the amplitudes and affects these the same for all components, it does not alter the wave form of the reproduced signal, but does affect its magnitude very materially.

Thus in a carrier telephone system fluctuations in the phase of the local carrier are much more serious when both side-bands are transmitted than when one is suppressed, the only effect then being an unimportant phase distortion. In a carrier telegraph system, however, the amplitude fluctuations which occur when both side-bands are transmitted may not be particularly troublesome since telegraph receiving apparatus is designed to operate over quite a range of signal intensity. The phase distortion occurring in single side-band transmission is however serious. It may perhaps be considered fortunate that the requirements as to phase regulation are least severe in telephony with a single side-band and in telegraphy with both side bands, since these modes of operation appear on other grounds to be the most practical for the two cases.

In comparing single and double side-band transmission it is interesting to note that for equal sending power, the power of the reproduced signal component is twice as great with two side-bands as with one. However, the power of the same frequency resulting from static is also twice as great, so that the ratio of signal to interference is the same in both cases. To show this, let B_1 be the amplitude of a component of the single side-band and B_2 that of each of the corresponding components of the double side-band. Then equality of power gives

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$$B_1^2 = 2B_2^2. \tag{31}$$

For the single side-band the amplitude of the reproduced component is

$$R_1 = g\,B_1, \tag{32}$$

where g is a constant of proportionality. The power,

$$P_1 = \frac{1}{2} g^2\, B_1^2 = g^2\, B_2^2. \tag{33}$$

(The resistance is here omitted as it is assumed constant thruout.) For the double side-band, since the two components are in phase, the resultant amplitude,

$$R_2 = 2\,g\,B_2, \tag{34}$$

and the power,

$$P_2 = 2\,g^2\,B_2^2 = 2\,P_1. \tag{35}$$

If the static be assumed to approximate an impulse, the amplitudes of all its components will be sensibly the same. If we call this amplitude S, then, in the case where the receiving circuit admits only one side-band, the amplitude of the reproduced interfering current of the frequency of the signal component is

$$I_1 = g\,S, \tag{36}$$

and its power,

$$W_1 = \frac{1}{2} g^2\, S^2. \tag{37}$$

With both side-bands this interfering current is made up of two equal components derived from the static components of frequencies $\frac{p+q}{2\pi}$ and $\frac{p-q}{2\pi}$ respectively. The phase difference ϵ between these two will be accidental, so for any one case the resultant amplitude,

$$I_2 = 2\,g\,S\cos\epsilon, \tag{38}$$

and the power,

$$W_2 = 2\,g^2\,S^2\cos^2\epsilon. \tag{39}$$

As all values of ϵ are equally probable, we may average W_2 with respect to ϵ, whence

$$\overline{W}_2 = g^2\,S^2 = 2\,W_1. \tag{40}$$

There is then no choice between one and two side-bands on the basis of the ratio of signal to interference, With a single side-band, the major advantage of economy in frequency range is secured at the expense of the minor disadvantage that to give

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the same response the amplification of the receiving set must be greater by a factor of two in power, or about three miles of standard cable.

Use of Non-synchronous Local Carrier

In practice, however, unless the receiving carrier frequency is controlled by the same source as the sending carrier, it is rather difficult to maintain even the frequencies alike, to say nothing of the phases. Let us suppose that the local carrier is out of synchronism by a small amount, n. Consider first the simplest case where the carrier is suppressed and one side-band only is transmitted. The local carrier beating with each component of this side-band gives a component of normal amplitude, but of a frequency differing from that of the original signal component by n. That is, all the frequencies of the speech are raised or lowered by the same amount, n. This must alter the wave form very decidedly, but the surprising thing is that in telephony the intelligibility is not seriously affected when the difference is made as much as fifty cycles or so. The apparent pitch of the voice changes, of course, as n is varied.

If the carrier is transmitted, either intentionally or thru incomplete suppression, the situation is less favorable to asynchronous reception. The two carriers then beat together, giving a component of frequency n which may be troublesome if the received carrier is large. However, its frequency is generally below the voice range, and so it can be suppressed by a filter in the detector output. In addition the received carrier beating with the side-band gives the components of the original signal. These are superposed on the displaced speech from the local carrier, the corresponding components of the two differing in frequency by n. As a result, the two sounds beat together just as two tuning forks would. For very small differences in frequency a periodic rise and fall in intensity is heard. When the difference is increased so that the individual beats can no longer be distinguished, a sensation of roughness results. And when the difference is made still greater the two waves may be heard as separate sounds of noticeably different pitch. The prominence of this beating effect depends, of course, upon the relative magnitude of the two carriers, since the two sets of speech currents are in the same ratio as the two carriers.

This effect of the received carrier may be very much reduced, and in the ideal case entirely eliminated, by the use of a balanced

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detector similar in structure to the balanced modulator of Figure 3. It can be shown that with such a circuit the combination frequencies resulting from any two components applied at S are neutralized in the output circuit, while the combination of each with the carrier applied at C is transmitted. Thus if the side-band and received carrier enter together at S, the components having the original signal frequencies are eliminated and only the displaced components remain.

When the other side-band is added, the situation is still further complicated. In the absence of received carrier the local carrier and one side-band give a set of components the frequencies of which are greater than those of the signal by n, while the carrier and other side-band give a set less by the same amount. These two sets combine in much the same way as do the displaced and normal speech obtained with a single side-band and received carrier. Here, however, the beat frequency is $2n$. Also, as the two sets are equal in amplitude, the beats will be much more pronounced, the intensity falling to zero each time the two waves are in opposition. For slow beats the apparent pitch of the sound is half way between the frequencies of the two equal components, and so the normal voice frequency will be heard. With large frequency displacements of the carrier the two displaced speech waves, being of equal intensity, will be more easily distinguished than in the case of the single side-band.

It is interesting to note that this result, as well as the frequency shift that occurs with a single side-band, follows directly from the relations arrived at above for the phase displacement of a synchronous carrier. The non-synchronous carrier may be thought of as a synchronous one the phase of which is varied with the frequency of the departure from synchronism. With a single side-band it was shown that a phase displacement of the carrier affects only the phase of the reproduced component and that it changes this by an amount equal to its own displacement. This progressive phase displacement in all the components of the reproduced wave is, of course, equivalent to a change in their frequencies equal to the frequency displacement of the carrier. With both side-bands present, a phase displacement was shown to have no effect on the phases but to change the amplitudes of the reproduced components by the factor $\cos \gamma$. Thus a progressive change in γ will cause a cyclic variation in amplitude having two minima for each cycle of γ: that is, a frequency of $2n$.

If the two side-bands are accompanied by the carrier there are added the beat note of the two carriers and the components

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of the original signal. The addition of a small amount of this speech of uniform amplitude to that of varying amplitude already present merely tends to make the variation slightly less pronounced. From the foregoing it appears that for telephony the most favorable condition for using a local carrier which is out of synchronism is that in which only one side-band is transmitted. Fairly considerable frequency variations are then permissible and asynchronous operation appears to have practical possibilities.

For telegraphy the case is quite different. In the first place the important components of telegraph signals are much lower in frequency, so that the side-band lies closer to the carrier, and a much smaller absolute displacement of the carrier frequency is needed to give the same effect as in the telephone case. Considering only such small displacements, it appears that the general addition or subtraction of frequencies which occurs with a single side-band will alter the shape of the signals quite seriously. The slow fluctuations in signal intensity which occur with both side-bands are probably less serious over most of the cycle. However, they might well cause some signals to be lost entirely each time the intensity passed thru zero.

For asynchronous reception, then, just as for the case of a local carrier displaced in phase, single side-band transmission is preferable for telephony and double side-band for telegraphy. The difficulties are of the same general nature in the two cases, but with the asynchronous carrier they are considerably greater. This is in agreement with the idea expressed above, that lack of synchronism may be looked upon as an aggravated case of phase displacement.

Research Laboratories of the American Telephone and Telegraph Company, and the Western Electric Company, Incorporated.

October 9, 1922.

SUMMARY: The modulation of a carrier wave by a signal wave and the subsequent reproduction of the signal wave are discussed in terms of the sustained sinusoidal components into which the various waves may be resolved. The conception of a modulated wave as being made up of a carrier component and two side-bands is explained.

The saving in frequency range resulting from transmitting a single side-band is emphasized. Carrier suppression and homodyne reception are shown to save sending power, increase receiving sensitiveness and aid in suppressing interference from both stations and static.

Equations are derived for the distortion of the reproduced wave in terms of that of the modulated wave. In general, both the amplitude and phase of each component of the signal depend on both the amplitudes and phases of the corresponding side-band components and of the carrier.

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The effect on the signal of various typical distortions of the radio wave is examined for both single and double side-band transmission, as is also that of altering the phase of the locally supplied carrier and of altering its frequency. The resulting distortion of the signal is found, in general, to be more serious for telephony when both side-bands are used and for telegraphy when only one is used.

It is also shown that the reproduced signal has twice the power when both side-bands are transmitted as when the same sending power is concentrated in one. The signal to static ratio is, however, the same in both cases.

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Further Discussion on "Resistance and Capacity of Coils at Radio Frequencies"*

By J. H. Morecroft

A. Press (by letter): The experiments of Professor Morecroft in endeavoring to check up the work of Dr. Breit are so important a matter for radio science that it may be of value to emphasize the crowning assumption of Dr. Breit's mathematical developments.

Turning to "The Physical Review" for June, 1921, equation (4) of the article on "The Distributed Capacity of Inductance Coils," it will be seen that the assumption is made that the charge density at any point x is a function of x times the rate of change of the current at any point taken as a standard. The formula in question is

$$Q(x) = a(x) \cdot \frac{di_1}{dt} \tag{4}$$

In reality from the experiments of Professor Townsend of Oxford, and others, the wave distribution of current, so far as its plural nodal distances are concerned, is a function of the frequency. This frequency function can be of the resonant type, or even of the *dissonance* type as the writer has indicated elsewhere. Much depends on the geometrical constants of a coil with respect to the particular frequency. It would be too much to expect that a formula of the simplicity (1)

$$L(C+C_o) = \frac{1}{w^2} \tag{1}$$

should hold for both cases indicated herewith.

G. Breit (by letter): Referring to the second paragraph of Mr. Press' letter: "Turning to . . . at any point x is a function of x *times the rate* . . ." The part in italics is wrong, as is seen from

*See page 287 of the August, 1922 (volume 10, number 4), issue of the Proceedings of The Institute of Radio Engineers.

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the formula (4) quoted. This formula is reproduced not quite correctly by Mr. Press; the Latin a being used for the Greek α.

I do not think it is correct to call the assumption discussed by Mr. Press the *crowning* (?) assumption of my deduction. The first paragraph of my synopsis introduces C_0 as the quantity which is experimentally known to satisfy: $L(C+C_o)=\frac{1}{\omega^2}$. My problem was to calculate C_0 within the range of ω for which the above relation is reasonably true. The same point of view is brought out in the summary. The absolute validity of the equation $L(C+C_o)=\frac{1}{\omega^2}$ would be, of course, untrue. The factors which make this equation a good approximation I tried to consider in the section: "Explanation of constancy of C_0" (pages 669-671, "Physical Review"). As shown there within a certain range the formula may be expected to hold.

The assumptions underlying my derivation I tried to summarize on page 650 under 1, 2, 3, 4, 5. These are essentially reviewed on the bottom of page 656 and the top of page 657. The point of view taken towards C_0 is brought out particularly under (h) (page 657).

In Mr. Press' letter $\frac{1}{w^2}$ in (1) should be $\frac{1}{\omega^2}$.

It is difficult for me to be sure that I understand correctly the section of Mr. Press' latter just after (4). He certainly cannot mean that I do not consider the dependance of current distribution on the frequency because this is the fundamental point in my derivation. It would seem then that he considers the fact that a coil can vibrate in different modes. This fact has been known to Drude and is generally obvious by analogy with an organ pipe. The difficulty is taken care of by the fact that the range in which $L(C+C_0)=\frac{1}{\omega^2}$ is used deals only with one mode.

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DIGESTS OF UNITED STATES PATENTS RELATING TO RADIO TELEGRAPHY AND TELEPHONY*

ISSUED OCTOBER 31, 1922–DECEMBER 19, 1922

BY

JOHN B. BRADY

(PATENT LAWYER, OURAY BUILDING, WASHINGTON, D. C.)

1,433,599—R. Brown, filed July 2, 1921, issued October 31, 1922. Assigned to American Telephone and Telegraph Company.

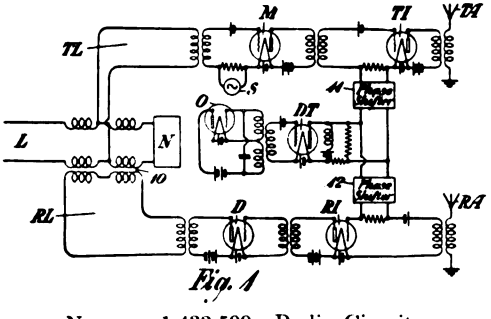

Fig. 1

NUMBER 1,433,599—Radio Circuits

RADIO CIRCUITS for an electron tube transmitter and receiver whereby the transmitting and receiving apparatus may be operated in close proximity to each other at the same station without interference, and wherein two-way communication may be had without mechanical switching from transmitter to receiver. In this circuit Figure 1, advantage is taken of the commutating characteristic of an electron tube for shifting the operation of the system from transmission to reception. *R A* indicates the receiving antenna connected to circuit *R I* functioning as an interrupter and from thence to receiving apparatus which may transmit the signal energy to a line wire telephone circuit *L*. *T A* represents the transmitting antenna connected to circuit *T I* which also functions as an interrupter and from thence to a suitable modulator *M* and source of continuous wave energy *S* with the line wire system *L*. An oscillator *O* generates an oscil-

*Received by the Editor, January 5, 1923.

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lating current which is passed thru a distorting circuit *D T* and is then alternately superposed on the two interrupters *T I* and *R I*. If a wave of proper polarity is superposed on the normal potential of the grid circuit of the tube *T I*, the tube may be caused to operate upon the straight amplifying portion of its characteristic during the flat topped interval of the supplied wave, so that the modulated radio frequency will be freely transmitted thru the interrupter *T I* to the antenna *T A*. The tube *R I* will at the same moment have a pulse of current supplied to its grid, of such a character as to prevent transmission. The next succeeding half-wave will be in the opposite direction, however, and will shift the operating point of the tube *R I* to the amplifying portion of its characteristic, so that the received radio oscillations will be free to be passed thru the interrupter and impressed upon the detector *D*. Transmitting and receiving will, therefore, take place alternately at a high frequency rate determined by the frequency of the oscillator *O*.

1,434,064—A. Monteilhet, filed September 15, 1913, issued October 31, 1922.

METHOD OF AND APPARATUS FOR FACSIMILE TELEGRAPHY, in which synchronized means are provided for periodically varying the local circuit of both the transmitter and receiver with means for sending a signal energy impulse of constant value from the transmitter to the receiver at the time the transmitter energy reaches a predetermined value. A galvanometric optical receiver is employed for the reception of cliches, reliefs, photographs, and the like transmitted.

1,434,707—E. W. Kellogg, filed April 21, 1921, issued November 7, 1922. Assigned to General Electric Company.

RADIO RECEIVING SYSTEM, in which a plurality of receiving antennas are located at widely separated points having their receiving circuits interlinked by line wires with a central receiving station to which the signals may be conveyed and read. The transmission lines connecting the several receiving stations with the central station serve to transmit the local generator frequencies for each of the receivers from a single generator at the central station.

1,435,009—E. W. Kellogg and C. W. Rice, filed April 27, 1921, issued November 7, 1922. Assigned to General Electric Company.

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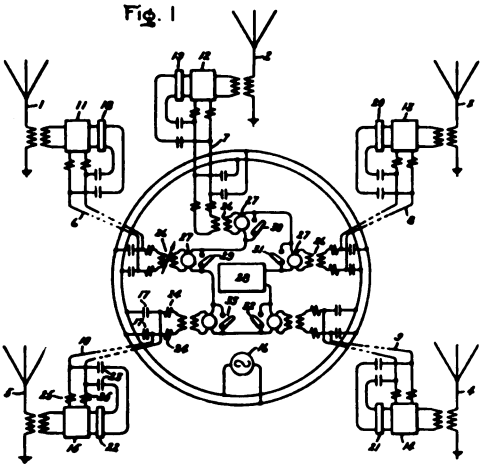
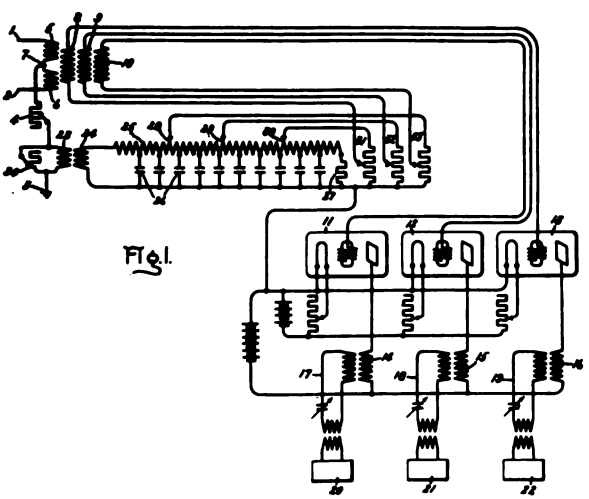


NUMBER 1,434,707—Radio Receiving System



NUMBER 1,435,009— Radio Receiving System

RADIO RECEIVING SYSTEM employing a plurality of receiving sets connected to an antenna system at selected points along the antenna whereby disturbing signals do not interfere with reception in the different receivers. The antenna is aperiodic, so that the strength of the signaling currents produced therein is substantially independent of the wave length. Incoming signals are impressed upon the input circuits of a plurality of electron discharge amplifiers at potentials produced in the antenna at different selected points. In order to improve the re-

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ception, means are provided for impressing upon each of these input circuits a current selected from another point in the antenna which will be of the proper intensity and phase to neutralize in each receiving set disturbing currents produced therein either by interference from undesired waves or by strays. Each of the output circuits of the amplifiers has associated therewith a resonant circuit which is tuned to the frequency of one of the signaling waves which it is desired to receive, and these resonant circuits are associated with the respective receiving sets.

Reissue 15,495—I. Langmuir, filed January 29, 1920, issued November 21, 1922. Assigned to General Electric Compant.

"Wireless" Signaling System. This patent relates to a heterodyne receiver employing an electron tube circuit with a coupling between the grid and plate circuits, one of the circuits being resonant, whereby local oscillations may be produced of a different frequency from that of the oscillations to be received. Each of the circuits are coupled with the antenna system. This patent was originally granted as 1,313,093, dated August 12, 1919, on an application filed March 11, 1916.

1,435,455—H. P. Donle, filed February 2, 1920, issued November 14, 1922. Assigned to the Connecticut Telephone and Electric Company, Incorporated.

Electric Current Controlling Device in the form of a tube construction having a filament contained within an exhausted vessel and two outer electrodes spaced apart on the outer surface of the tube, one serving as an anode or plate and the other as a control electrode.

1,435,941—J. Robinson, filed November 12, 1918, issued November 21, 1922.

Radio Direction Finder in which a pair of coils in vertical planes are set at an angle to one another, preferably at a right angle, and are rotated about a vertical axis until no appreciable difference in strength of signal is found, when the effect of that coil lies at right angles to the direction of arrival of the waves, the bearing of which is desired, is superposed positively or negatively upon the effect of the other coil. The bearing can then be determined by the position of the first coil. A switching arrangement is provided so that one coil may be temporarily cut out and an equivalent inductance inserted in the circuit.

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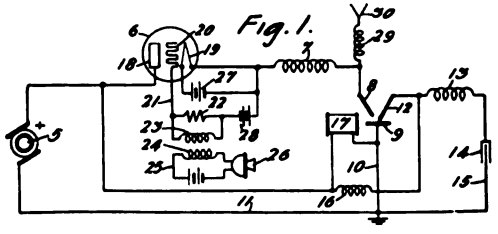
The invention is illustrated in connection with a direction finder installation in the fuselage in an aircraft.

1,436,252—R. A. Heising, filed December 27, 1918, issued November 21, 1922. Assigned to Western Electric Company, Incorporated.



NUMBER 1,436,252—System for Producing Modulated Waves

SYSTEM FOR PRODUCING MODULATED WAVES, utilizing an arc generator for telegraphy. An electron tube is connected in circuit with the arc system. Referring to the drawing, the generator 5 supplies a direct voltage to the circuit 15 and condenser 14 which periodically discharges across the electrodes 9 and 12 and causes simultaneous discharge across the electrodes 8 and 9. The amplitude of the discharge across the electrodes 8 and 9 will depend largely upon the instantaneous condition of the device 6. Thus while the amplitude of the discharge may be made to vary, the frequency thereof will remain substantially constant. Altho the discharge across electrodes 9, 12 may consist of a small amount of energy, it may serve to control the discharge of a much larger amount of energy across the electrodes 8, 9. The device 6 acts as an amplifier and reproduces in amplified form the impedance changes in or the current changes thru the device 26.

1,436,676—M. H. Petersen, filed October 21, 1921, issued November 28, 1922.

SYSTEM FOR "WIRELESS" TRANSMISSION OF WRITING, PICTURES, AND THE LIKE, in which part of the current circuit of an alternating current generator connected to the transmission leads is short-circuited by means of a contact arrangement, which is so actuated by means of the writing at the sending station that the short-circuiting is started or interrupted by means of a contact needle passing over the written lines. The received oscil lating current energy is combined with the energy of a separately

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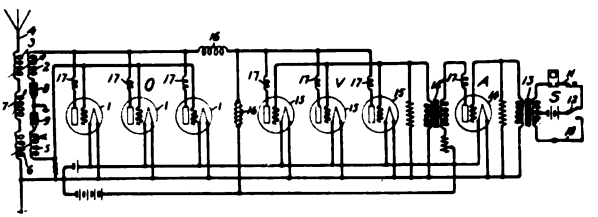
produced auxiliary current the frequency of which is slightly different from the frequency of the received current, producing a beat frequency operating an oscillograph. Another beat frequency is produced differing from the first beat frequency and the second beat frequency combined to produced synchronized mechanical movement.

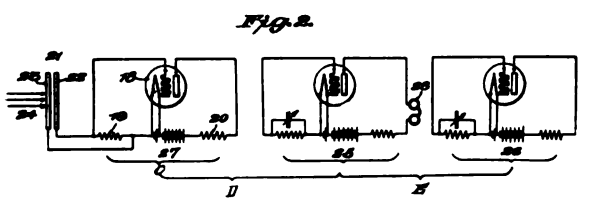
1,437,021—J. C. Schelleng, filed May 11, 1921, issued November 28, 1922. Assigned to Western Electric Company, Incorporated.



NUMBER 1,437,021—Electron Discharge Device Circuits

ELECTRON DISCHARGE DEVICE CIRCUITS. This patent shows a circuit for an electron tube transmitter in which small inductance coils are connected in the individual plate circuits of the several vacuum tubes in the system. In the case of 50 watt tubes in parallel for radio transmission, these inductances have a value of the order of 10 microhenries. These inductances serve as choke coils for preventing the production of undesired or parasitic oscillations. In the diagram the choke coils are indicated by reference number 17.

1,437,240—E. C. Hanson and W. L. Carlson, filed May 28, 1920, issued November 28, 1922.



NUMBER 1,437,240—Apparatus for Detecting Minute Values of Energy

APPARATUS FOR DETECTING MINUTE VALUES OF ENERGY. This invention relates to an apparatus for detecting slight varia-

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tions in frequency of an oscillating current which might be brought about by slight forces, such as light rays striking the plates of a condenser suitably connected in the oscillating circuit. The principle involved in the apparatus is the heterodyning of two or more oscillating electric currents to produce a beat, the frequency of which will be determined by the natural constants of the circuits and the external influence of a particular frequency acting upon one of the circuits. The apparatus is intended, among other things, as a measuring device for minute forces such as light rays.

1,437,400—W. W. Conners, filed June 12, 1919, issued December 5, 1922.

METHOD AND APPARATUS FOR INDICATING THE GEOGRAPHICAL LOCATION OR MOVEMENT OF BODIES, employing a similitude board on which the movement of a body in miniature at the transmitter causes a reproduction of the movement at the receiver.

1,437,498—L. De Forest, filed June 16, 1916, issued December 5, 1922. Assigned to De Forest Radio Telephone and Telegraph Company.

OSCILLION, in which the filament, grid, and plate electrodes are arranged with the filament lengthwise in the tube, the grid wound around a frame which carries the filament and the plate supported on the interior of the wall of the tube surrounding but out of contact with the grid.

1,437,607—E. L. Mueller, filed November 18, 1920, issued December 5, 1922.

ELECTRON TUBE, in which a mercury arc is formed within a refractory chamber disposed within a grid electrode surrounded by a plate electrode in the usual form of an electron tube. The mercuty arc is used as a source of electrons for the purpose of avoiding the limited life of the usual filamentary cathode tube.

1,437,772—J. B. Nowland, filed June 13, 1922, issued December 5, 1922. Assigned two-thirds to Simon Bitterman.

RADIO APPARATUS. This invention relates to a vernier tuning coupler for a radio receiver. The coupling system is arranged with a primary winding in the antenna ground circuit and a set of two secondary windings each of which can be adjusted inde-

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pendently relative to the primary winding. One of the secondary windings permits a broad adjustment of coupling for tuning purposes while the other secondary winding permits a vernier adjustment of coupling whereby the secondary circuit is accurately tuned for reception of incoming signals on different wave lengths.

1,438,290—W. E. Beakes, filed July 1, 1918, issued December 12, 1922. Assigned to United Fruit Company.

An Antenna System is shown in this patent whereby an antenna conductor may be reeled on and off of a metallic drum to secure the desired period of antenna system. The antenna conductor is normally contained upon a metallic drum. One end of the conductor is secured to an insulated cord which is wrapped upon another drum. By winding or unwinding the cord different optimum length of the antenna is secured for a particular wave length.

1,438,347—R. A. Weagant, filed March 6, 1920, issued December 12, 1922. Assigned to Radio Corporation of America.

Receiving Apparatus for Radio Signals for use with a plurality of antennas situated at a distance from each other and connected to the same receiving circuit. The system may employ large loop collectors constructed at great physical distances apart. In a system of this kind it is usual to have long horizontal leads going into the receiving station, but these leads pick up undesired signals and static. In the present invention electron tube amplifiers are arranged immediately adjacent each of the antennas for amplifying the energy received on the antenna system and conducting it to the receiving station located at a distance. The idea is to amplify the signal and static current derived from the cages so that they will be large compared with those derived from the leads. In a modified circuit the energy of each of the antennas is converted to audio frequency and then conducted over the leads to the receiver.

1,438,567—R. E. Winstanley, Jr., filed February 1, 1919, issued December 12, 1922.

Radio Signaling Apparatus in which the transmitter is controlled by an automatic circuit closer for causing the transmission of any selected number of a plurality of pre-determined signals or messages. The apparatus is particularly intended for

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the transmission of distress signals from ships at sea without the attention of an operator. The transmitter is contained within a cabinet which is normally closed, the apparatus therein being inoperative. When the cover of the cabinet is opened the transmitter circuit is closed and start signals are transmitted. By the movement of control switches different messages may be transmitted by the automatic circuit closer sending out such expressions as "S O S," "All is well," "Sinking," or other expressions.

1,438,969—L. R. Spengeman, filed September 17, 1918, issued December 19, 1922. Assigned to Western Electric Company, Incorporated.

VACUUM TUBE in which a resilient wire spring in the shape of a *V* with spring coils between its ends is arranged in the tube for maintaining the filament taut at all times.

1,438,988—L. Espenschied and Herman A. Affel, filed September 30, 1919, issued December 19, 1922. Assigned to American Telephone and Telegraph Company.

HIGH FREQUENCY TRANSLATING CIRCUITS for telegraphy, in which an iron core modulating device is employed having a plurality of windings. An input circuit containing a source of current of one frequency is connected with one winding on the core and a second input circuit containing a source of current of a different frequency is connected with another winding on the core. Filters are interposed in each circuit adapted to transmit only the current of the frequency generated by the source associated with the respective circuits. A third circuit containing a source of direct current is connected with a third winding with a filter interposed in the circuit. A fourth winding on the modulating device is connected with the transmitting system such as an antenna ground.

1,438,989—L. Espenschied and Herman A. Affel, filed September 30, 1919, issued December 19, 1922. Assigned to American Telephone and Telegraph Company.

HIGH FREQUENCY TRANSLATING CIRCUITS, employing an arc generator as a source of oscillations. An input circuit is arranged to modulate the oscillations of the arc circuit in accordance with voice frequencies with a filter so connected in the input circuit as to exclude therefrom undesired oscillations.

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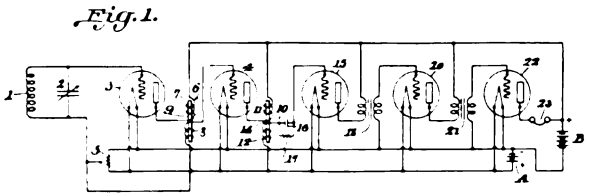
1,439,363—J. H. Hammond, Jr., filed December 13, 1919, issued December 19, 1922.

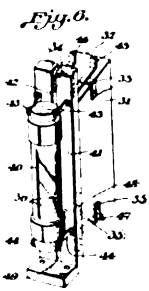
Receiving System for Radiant Energy, particularly adapted for submarine vessels. The antenna is arranged with an entering insulator with adjacent ring contacts on the insulator which when submerged in salt water establishes a circuit which renders inoperative control apparatus within the submarine. The idea is to render the control unresponsive to interfering signals which would normally be caused by salt water washing over the antenna during transmission of control signals.

1,439,495 H. M. Williamson, filed September 25, 1922, issued December 19, 1922.

Radio Receiving Apparatus, including a thermionic amplifier with a high reactance and a condenser shunted across the grid filament circuits for preventing inherent oscillations in the grid circuits.

1,439,562 P. D. Lowell, filed September 9, 1921, issued December 19, 1922. Assigned to Radio Instrument Company Incorporated.





Number 1,439,562 —Amplifying System

Amplifying System, comprising a plurality of electron tube stages with interchangeable coupling means between the output circuit of one tube and the input circuit of a succeeding tube whereby a coupling transformer wound for a particular band of wave lengths may be quickly removed from the circuit and a different transformer wound for a different band of wave lengths may be plugged in. The invention contemplates a series of transformers efficiently transparent to one band of frequencies while opaque to another band of frequencies which may be sub-

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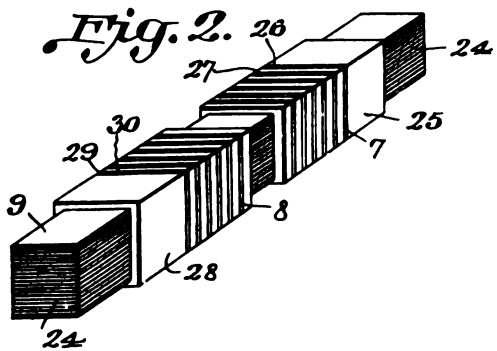
stituted one for another to transfer efficiently the different bands of frequencies from one electron tube stage to another.

1,439,563—P. D. Lowell, filed September 9, 1921, issued December 19, 1922. Assigned to Radio Instrument Company, Incorporated.



NUMBER 1,439,563—Radio Frequency Transformer

RADIO FREQUENCY TRANSFORMER, in which the primary and secondary windings each comprise a group of coils, each coil having a plurality of fine wire turns wound along the periphery of an insulation material and spaced from an adjacent coil, the one group of coils being spaced from the other group of coils to determine the coupling of the windings for a particular band of frequencies. The transformer is designed to operate over a limited band of frequencies. Several different transformers are provided having different coupling characteristics and arranged to be plugged in between the electron tube stages to pass the different waves of wave lengths.

1,440,142—G. Fuegel and Herman Schmid, filed December 27, 1918, issued December 26, 1922. Assigned to Apollo Magneto Corporation.

ELECTRICAL CONDENSER designed particularly for magneto installations. The condenser is supported by a binding screw passing thru one of the sets of armatures and securing the condenser unit in position within a casing.

LIST OF RADIO TRADE MARKS PUBLISHED BY PATENT OFFICE PRIOR TO REGISTRATION

(*The numbers given are serial numbers of pending applications*)

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161,010—"MATCHED TONE" for telephone head sets. C. Brandes Inc., New York, N. Y. Claims use since about March, 1914. Published October 31, 1922.

161,028—"SIMPLEX" arranged in ornamental design—for radio apparatus. Simplex Radio Co., Philadelphia, Pennsylvania. Claims use since on or about March 16, 1921. Published October 31, 1922.

151,143—"BEACON" arranged in ornamental design—for current rectifiers, transformers and batteries. Beacon Rectifier Company, Hyde Park, Massachusetts. Claims use since January 1, 1918. Published November 7, 1922.

160,500—"RADIOBAT" arranged in ornamental design—for radio receiving apparatus. Multiple Storage Battery Corporation, Dover, Delaware, and New York, N. Y. Claims use since March 6, 1922. Published November 7, 1922.

165,194—"BESTONE" arranged in ornamental design—for radio receiving apparatus. Henry Hyman and Co., Inc., New York, N. Y. Claims use since April, 1922. Published November 7, 1922.

168,367—"RESUNDA" in ornamental letters, for radio receiving apparatus. Jones-McKee, Inc., New York, N. Y. Claims use since July 15, 1922. Published November 7, 1922.

168,368—"HY-TONE" for radio receiving apparatus. Jones-McKee, Inc., New York, N. Y. Claims use since July 15, 1922. Published November 7, 1922.

168,529—"THE CLARION" in ornamental letters—for loud speakers. Maurine W. Hirshfield, doing business as Marfield Radio Mfg. Co., New York, N. Y. Claims use since July 1, 1922. Published November 7, 1922.

168,683—"L M" in ornamental design—radio transmitting and receiving apparatus. Maline-Lemmon Laboratories, New York, N. Y. Claims use since May 5, 1922. Published November 7, 1922.

168,768—"HUSH-A-PHONE" in ornamental design—for telephone muffler. Hush-A-Phone Corporation, New York, N. Y. Claims use since March 3, 1922. Published November 7, 1922.

161,691—"LONG DISTANCE" for radio apparatus. Chicago

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Radio Laboratory, Chicago, Illinois. Claims use since on or about July 1, 1919. Published November 14, 1922.

161,728—"PEERLESS" for radio apparatus. Thompson-Levering Company, Inc., Philadelphia, Pennsylvania. Claims use since January, 1909. Published November 14, 1922.

162,947—"DAYTON" for radio apparatus. The A-C Electrical Mfg. Co., Dayton, Ohio. Claims use since on or about August 1, 1922. Published December 26, 1922.

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PROCEEDINGS OF
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Volume 11 | APRIL, 1923 | Number 2

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THE WORK OF THE INTERNATIONAL UNION OF SCIENTIFIC RADIO TELEGRAPHY*

By

J. H. Dellinger

(Chief of Radio Laboratory, United States Bureau of Standards, Washington, D.C.)

This organization is not, as the name might perhaps suggest, a radio telegraphers' union. It is the world organization for the promotion of radio research on an international scale. It was begun in July, 1919, under the auspices of the International Research Council. It is organized:

1. To promote the scientific study of radio communication.
2. To aid and organize researches requiring cooperation on an international scale and to encourage the discussion and publication of the results of such researches.
3. To facilitate agreement upon common methods of measurement and the standardization of measuring instruments.

The work is actually carried on thru the activities of the National Sections, which have been organized in the United States, Belgium, England, France, Italy, and Norway. Steps are being taken to create such Committees also in Australia, Holland, Japan and Spain.

The International Union itself is a rather simple organization framework for carrying on the international phases of the administrative work. It is similar to the various other international unions: of astronomy, geophysics, mathematics, chemistry, and so on. The officers are a president (General Ferrié, France), four vice-presidents (Dr. L. W. Austin, United States; Dr. W. H. Eccles, England; Dr. Vanni, Italy; Dr. Bjerknes, Norway), and a general secretary (Dr. R. B. Goldschmidt, Belgium). The office is located in Brussels. One of the principal duties of the international officers is the calling of a general meeting of the International Union every three years. Delegates from the several National Sections attend the general meeting. The second such meeting was held in Brussels in

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July, 1922. This meeting organized four international "commissions" for the purpose of correlating the work done by the several national committees on the corresponding subjects. The membership of the international commissions is as follows:

	President	United States	England	Belgium	France	Italy	Norway
Methods of measurement and standards	Abraham	Dellinger Goldsmith	Glazebrook Dye F. E. Smith E. Murray	Henrion Tricot Corteil	Abraham Jouaust Bethenod	Vanni Vallauri	Vegard Petersen
Radio wave transmission phenomena	Austin	Austin Alexanderson Taylor	Howe F. F. Smith	DeDonder Philipp son	Mesny Perot	Artom Pession	Petersen Engset Cythfeldt
Atmospheric disturbances	Eccles	Austin Squier	Eccles	Wibier Jaumotte	Ferrié Rothe Marius Latour	Pession Sacco Le Dir. de l'Observatoire de Monte Cassino	Bjerknes Skolen Devik
"Liasons"	Vanni	Kennelly	Campbell Swinton	Goldsmith Pere Lucas	Jullien Brenot	Vanni Bardeloni	Not yet designated

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The American Section was organized on October 26, 1920, under the auspices of the National Research Council, in Washington. The American Section is made up of an Executive Committee and six technical committees. The Executive Committee consists of: two officers of the National Research Council ex-officio, one member each from the Army, the Navy, the Department of Commerce, the Institute of Radio Engineers, four members at large appointed by the President of the National Academy of Sciences, and (ex-officio) officers of the International Union resident in the United States. The personnel, for 1922 to 1925, is:

L. W. Austin, *Chairman*

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A. Hoyt Taylor

E. M. Terry

The technical committees are briefly described in the following. In every case, persons interested in participating in the work are invited to communicate with the Chairman of the Committee.

1. Radio Wave Transmission Phenomena.—Chairman, Dr. L. W. Austin, Naval Radio Research Laboratory, Bureau of Standards, Washington, D. C. One of the principal kinds of work is the measurement of radio wave field intensity at receiving stations, observing particularly diurnal and seasonal variations, and the comparison of observed values with formulas for the determination of the laws of transmission under various conditions by day and by night, over sea and various kinds of topography, sunset and sunrise effects, fading, aurora, local absorption phenomena, and so on. Comparison of results with different types measuring apparatus is another part of the work. Experiments indicate agreement between results obtained with the telephone signal comparator of Dr. Austin and

[1] W. Duane, in 1923.

[2] A. D. Flinn, in 1923.

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the radio-frequency comparison method of the Western Electric Company. For the assistance of participants in this work, certain large stations send special signals daily. These signals give the letters URSI and a dash lasting two minutes. The letters URSI are the initials, arranged as in the French equivalent of International Union of Scientific Radiotelegraphy. Even for stations in the following list which are not transmitting these special signals, observations on the field strength of the waves are worth while, since great accuracy is not required.

STATIONS NOW TRANSMITTING U. R. S. I. SIGNALS

	Greenwich Time	λ	Approximate Radiation Height	Approximate Antenna Current
Eiffel Tower	10 h.35 m.	2,600 m.	85 m.	85 amp. (spark)
Nantes....	14 h.15 m.	9,000 m.	135	180
Bordeaux..	19 h.55 m.	23,400 m.	170	480
Rome	16 h.	10,500 m.	120	100

The following American stations are expected to begin sending URSI signals in the near future.

	λ	Approximate Radiation Height	Approximate Antenna Current
New Brunswick, New Jersey	13,600 m.	66 m.	590 amp.
Radio Central (Long Island, New York).....	16,800	80	702
Marion, Massachusetts.....	11,620	66	600
Annapolis, Maryland..... (Sends time signals at 16 h. 55 m.).....	17,200	130	250

The following British stations are expected to send URSI signals.

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Leafield
Northolt
Horsea
Kidbrook
Constantinople
Clifden
Carnarvon

A large amount of work in the field of this committee has already been done by several observers in various parts of the world, particularly by Dr. Austin, chairman of the Committee. Results are published in the PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS, which has been designated as the official organ of publication of the American Section. There are various subordinate problems also within the purview of this committee, such as the angle of tilt of a wave front under various topographical conditions and for various types of waves.

1a. VARIATIONS OF RADIO WAVE DIRECTION.—Chairman, Commander A. H. Taylor, Naval Aircraft Radio Laboratory, Anacostia, D. C. This is a Subcommittee of Committee 1, Radio Wave Transmission Phenomena. The principal object of research is the variation of wave direction with time. Bending of the waves by topography or bodies of water is another object. The study of direction finder errors due to conditions at the receiving station is of collateral interest. The results of the observations taken to date indicate that the wave directions, for wave lengths above 4,000 meters, are subject to rapid and violent fluctuations; that the fluctuations are greater at night than by day; that the variations are probably greater at distances between 100 and 300 miles (160 and 480 km.) than for either shorter or longer distances; that the variations are less for damped than for undamped waves; that the variations are less over sea than over land. These conclusions are only preliminary, and more observational data on all these points are desirable. Further study in particular is desired on: (a) Short-wave direction variations of continuous wave and broadcasting stations; (b) damped wave variations; (c) night variations on wave length over 2,400 meters; (d) observations on all wave lengths at sea. Data may be taken either with or without compensation of minimum, that is, special means to reduce signal to zero at minimum position of direction finder; but the observer should always record the type of compensation used, if any.

2. ATMOSPHERIC DISTURBANCES.—Chairman, Commander

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A. H. Taylor, Naval Aircraft Radio Laboratory, Anacostia, D. C. The work includes measurement of the intensity and direction of propagation of atmospherics ("strays", "static"), and daily and seasonal variations. The problem is complicated by the numerous types of atmospherics that occur. The rumbling type, which is the most important, seems to consist of a spectrum of strongly damped waves. It is frequently directive, that is, comes from a definite direction. Thus a considerable portion of the atmospherics in the United States appear to come from the region of Texas. The particular subjects on which work should be done are: (a) directivity of the various types of atmospherics; (b) the question whether the various types are single pulses or a spectrum; (c) systematic measurement of intensity at different wave frequencies at different times of day; (d) systematic daily measurement of direction of directive types; (e) comparison with other phenomena such as sun spots, temperature, earth currents, weather, and so on.

3. Methods of Measurement and Standards.—Chairman, Dr. J. H. Dellinger, Bureau of Standards, Washington, D. C. The work of this committee is the development of radio measurements and standards, in general and also with particular view to the work of the other U.R.S.I. committees. One of the first problems calling for extensive observations is comparison of the wave frequency standards in use by measurements of wave frequency of stations transmitting waves of known frequency. Standard signals of this kind are transmitted from the Bureau of Standards about once a month; announcements of exact date are given in the Radio Service Bulletin.[3]

Measurements on the wave frequency of the high-power stations listed under 1 above are of value when made simultaneously by two or more observers. Standard wave lengths are transmitted by the Eiffel Tower and Lyons stations in France on the first and fifteenth of each month. The transmissions are between 18:00 and 18:30 Greenwich time, on approximately 5,000, 7,000, 10,000, and 15,000 meters. Another part of the work is improvement and standardization of methods for measuring field intensity of received waves and atmospherics, including the relating of signal intensity to field intensity, and the development of recording apparatus for continuous measurement of intensity. Collateral problems are the measurement of

[3] A monthly publication of the Department of Commerce, obtainable for 25 cents per year from the Superintendent of Documents, Government Printing Office, Washington, D. C.

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radiation resistance, current distribution, and effective height of antennas. The improvement of apparatus for routine observations of direction of waves and atmospherics is another line, including the study of "antenna effect," induction from surroundings, and use of balancing condensers. This committee also fosters progress on measurements and standards of capacity, inductance, resistance, current, and the like.

4. MEASUREMENT OF RADIATION CAUSING INTERFERENCE.—Chairman, Mr. E. F. W. Alexanderson, Radio Corporation of America, New York City. This committee has in view the measurement of what has been called "improper radiation" or "objectionable emissions." This involves the study of the distribution of wave field intensity with frequency. These measurements upon transmitted radio waves may be made in large part with the same apparatus used in the measurement of wave intensity, in work of committee on "Radio Wave Transmission Phenomena." The frequency breadth of a wave determines the interference it produces, whether such breadth is due to modulation, high signaling speed, spacing wave, actual decrement, harmonics, variation of generator frequency, and so on. Besides regular measurements on wave breadth, and perhaps prior to any extensive observations of that kind, there is need for: (a) devices to obtain resonance curve of wave form of a distant station modulated by speech or other arbitrary modulation; (b) simple analytic solution of problem of getting actual wave distribution from observed resonance curve, eliminating effect of measuring instrument; (c) mechanical device to replace analytic solution.

5. ELECTRON TUBES.—Chairman, Dr. F. B. Jewett, Western Electric Company, New York City. The character of this committee's work differs somewhat from those above. Research on electron tubes is necessarily of individual laboratory type. While there are many interesting and important research problems awaiting solution, the Committee's work as such has not yet been specifically outlined.

6. "LIAISON."—Chairman, Dr. A. E. Kennelly, Harvard University, Cambridge, Massachusetts. This is not strictly a technical committee. Its purpose is to facilitate the participation of operators, amateurs, and untrained observers in the recording of data of importance to the technical work of the International Union.

There is fruitful work for many years in the program as outlined above, which should have value not only for the better

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understanding and use of radio but also in the problems of geophysics, composition of the atmosphere, and other fields. Observers contemplating participation in the work should wherever possible plan to continue for at least a year, thus covering seasonal variations. Observations at sea are likely to be of particular value, as they have been fewest in the past, and because the radio phenomena are in general less complicated than on land.

It is believed that radio is unique among the few fields having special adaptability to a large-scale international research program. The phenomena that must be studied are world-wide in extent, and yet are in large measure subject to control of the experimenters. It is a field of work that has large possibilities for the future, and the surface only has been touched in the work done so far. Great progress can be made in the understanding of radio phenomena when widespread observations are taken, similar to the organized observational work on weather, earthquake, and terrestrial magnetic phenomena.

As previously stated, the chairman of each of these committees will be glad to receive communications from all persons who desire to co-operate in the work, and will furnish further information, data on methods of measuring, and so on. The American Section is especially desirous of gaining the co-operation of workers in universities and technical schools. The author of this article is Technical Secretary of the American Section, and will be glad to reply to general communications, requests for bibliographies or research suggestions, questions applying simultaneously to several of the Committees, and reports of work done.

Washington, D. C.

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RECEIVING MEASUREMENTS AND ATMOSPHERIC DISTURBANCES AT THE UNITED STATES NAVAL RADIO RESEARCH LABORATORY, BUREAU OF STANDARDS, WASHINGTON, NOVEMBER AND DECEMBER, 1922*

By

L. W. Austin

(United States Naval Radio Research Laboratory, Washington, D.C.)

(Communication from the International Union for Scientific Radio Telegraphy)

The observations given were taken as before.

It is seen that the afternoon fading noted during the summer has entirely disappeared, the three o'clock signals being generally stronger than those of the forenoon, due to the approach of sunset. The disturbances have fallen to a low value, being generally weaker than the signals.

During a part of November, the antenna current at Nauen was reduced to about 280 amperes while changes were being made in the station. This explains in part the low observed values of the Nauen signals during that month.

Lafayette did not send regularly during the forenoon in November and was not observed at all before noon during December.

The calculated signal intensities, assuming 480 amperes at Lafayette and 380 amperes at Nauen, are

$$E \text{ (Lafayette)} = 31.5.10^{-6} \text{ volts/meter}$$
$$E \text{ (Nauen)} = 15.3.10^{-6} \text{ volts/meter}$$

*Received by the Editor, February 21, 1923.

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RATIO OF AVERAGES

	Signal $\frac{\text{P. M.}}{\text{A. M.}}$	Disturbance $\frac{\text{P. M.}}{\text{A. M.}}$	A. M. Signal / Disturbance	P. M. Signal / Disturbance
		November		
$\lambda = 23{,}400$ m.	1.61	1.50	1.34	1.45
$\lambda = 12{,}500$ m.	1.55	1.48	1.02	1.07
		December		
$\lambda = 23{,}400$ m.	....	....	....	3.30
$\lambda = 12{,}500$ m.	1.01	1.21	1.83	1.52

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FIELD INTENSITY OF LAFAYETTE AND OF DISTURBANCES
($\lambda = 23{,}400$ m.) IN NOVEMBER, 1922, IN MICRO-VOLTS PER METER

	10 A. M.		3 P. M.	
Date	Signal	Disturbances	Signal	Disturbances
1	*	85	50.0	130
2	*	62	70.0	30
3	*	15	70.0	60
4	*	80	60.0	80
6	*	15	75.0	20
7	*	30	40.0	61
8	*	55	50.0	50
9	30.0	42	95.0	30
10	*	30	46.5	48
11	*	30	55.0	200
13	45.0	20	60.0	50
14	50.0	22	*	38
15	33.0	30	75.0	32
16	40.0	15	45.0	20
17	75.0	22	60.0	22
18	*	..	80.0	30
20	36.5	35	130.0	62
21	....	..	105.0	15
22	*	45	100.0	15
23	*	31	85.0	40
24	*	60	115.0	60
25	*	30	130.0	30
27	75.0	30	130.0	60
28	55.0	43	90.0	150
29	50.0	10	80.0	30
Average	48.9	36.4	79.0	54.5

*Not heard.
....Not taken.

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FIELD INTENSITY OF NAUEN AND OF DISTURBANCES ($\lambda = 12{,}500$ m.) IN NOVEMBER, 1922, IN MICRO-VOLTS PER METER

	10 A. M.		3 P. M.	
Date	Signal	Disturbances	Signal	Disturbances
1	36.0	40	17.0	30
2	19.0	30	11.0	20
3	43.0	10	34.0	30
4	22.0	50	21.8	60
6	32.0	6	22.0	8
7	34.0	8	28.0	56
8	14.0	20	....	....
9	12.0	28	29.0	10
10	8.5	8	29.0	12
11	6.3	8	18.5	60
13	12.0	8	9.5	30
14	13.2	10	37.0	21
15	6.0	10	38.5	17
16	7.2	5.5	30.0	20
17	11.0	8	31.0	8
18	8.5	6	25.7	20
20	4.5	15	*	30
21	....	....	*	8
22	7.2	18	3.0	10
23	6.8	18	37.0	21
24	25.7	40	47.0	40
25	27.0	15	31.2	15
27	*	16	....	....
28	*	15	....	....
29	19.0	6	*	16
Average	17.0	16.6	26.3	24.6

*Not heard.
....Not taken.

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FIELD INTENSITY OF LAFAYETTE AND OF DISTURBANCES ($\lambda = 23{,}400$ m.) IN DECEMBER, 1922, IN MICRO-VOLTS PER METER

	10 A. M.		3 P. M.	
Date	Signal	Disturbances	Signal	Disturbances
1	*	50	160.0	10
2	*	32	170.0	12
4	*	20	105.0	18
5	*	40	90.0	30
6	*	40	135.0	60
7	*	50	95.0	50
8	*	8	100.0	60
9	*	18	90.0	30
11	*	60	100.0	80
12	*	40	95.0	60
13	*	30	110.0	40
14	*	10	115.0	22
15	*	15	100.0	25
16	*	20	100.0	80
18	*	15	100.0	30
19	*	....	65.0	20
20	*	....	140.0	20
21	*	....	115.0	21
22	*	....	70.0	14
23	*	....	....	....
26	*	....	60.0	17
27	*	....	135.0	18
28	*	....	60.0	12
29	*	....	80.0	10
30	*	....	80.0	12
Average		29.0	103.0	31.3

*Not heard.
....Not taken.

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FIELD INTENSITY OF NAUEN AND OF DISTURBANCES ($\lambda = 12{,}500$ m.) IN DECEMBER, 1922, IN MICRO-VOLTS PER METER

	10 A. M.		3 P. M.	
Date	Signal	Disturbances	Signal	Disturbances
1	*	22	47.0	6
2	27.0	15	47.0	8
4	35.0	12	34.0	9
5	30.4	20	29.5	18
6	27.0	20	25.0	32
7	29.0	20	21.5	30
8	18.4	5	19.0	25
9	16.2	10	21.5	19
11	13.7	40	21.5	40
12	20.5	20	*	32
13	*	10	21.5	12
14	29.5	5	27.0	10
15	18.4	10	29.5	12
16	15.0	15	21.5	15
18	21.3	10	17.4	15
19	15.0	15	17.0	15
20	26.7	10	21.5	15
21	19.2	15	17.0	10
22	25.7	15	14.7	8
23	27.8	10	....	....
26	19.2	5	27.8	12
27	25.7	7	17.0	12
28	8.5	4	17.0	10
29	13.0	7	25.7	8
30	17.0	6	17.0	8
Average	24.0	13.1	24.2	15.9

*Not heard.
....Not taken.

SUMMARY: Field intensities of the signals from the Lafayette and Nauen stations, together with the simultaneous strengths of the atmospheric disturbances, are given for November and December, 1922.

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A COMBINED KENOTRON RECTIFIER AND PLIOTRON RECEIVER CAPABLE OF OPERATION BY ALTERNATING CURRENT POWER*

By

Albert W. Hull

(Research Laboratory, General Electric Company, Schenectady New York)

1—Introduction

The tube to be described is a combination of kenotron rectifier and pliotron with equipotential cathode. Equipotential cathodes, heated by radiation or bombardment from an internal filament, have long been in use in scientific investigations, and have frequently been suggested for pliotrons in order to obtain better amplifying and detecting characteristics.[1] It is obvious that a cathode of this kind in a pliotron could be heated by alternating current without producing appreciable alternating current hum in the output circuit.

The use of kenotron rectifiers for supplying plate voltage is also well known, and has become common practice in radio transmission. The combination of these two functions in a single four-element tube is new, so far as I know, and has interesting characteristics.

2—Principle

The principle of the combined kenotron and pliotron will be obvious from Figure 1, which shows a typical two-tube alternating current receiving equipment, with kenotron rectifier furnishing plate voltage for a pliotron detector. The heating battery for the pliotron cathode is omitted. The only point to be noted on this figure is the fact that the anode of the kenotron is connected directly to the cathode of the pliotron. It is evident that the operation would be the same if these two elements were combined into one, that is, if the kenotron were incorporated in the pliotron, and its anode used as pliotron cathode. The kenotron

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[1] Nicolson, United States Patent, 1,169,182; Morecroft, "Principles of Radio Communication," page 379.

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filament furnishes sufficient heat, by radiation, to enable this combined anode-cathode to emit electrons. The resulting tube and circuit is shown in Figure 2. The filament performs the

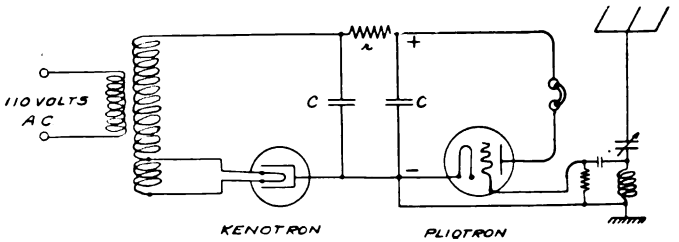

FIGURE 1 -Diagram of ordinary pliotron receiving circuit, with kenotron rectifier supplying plate voltage

double function of cathode for a kenotron rectifier that provides plate voltage, and radiant heater for the pliotron cathode. The cylinder which surrounds the filament acts at the same time as pliotron cathode and as anode of the kenotron rectifier.

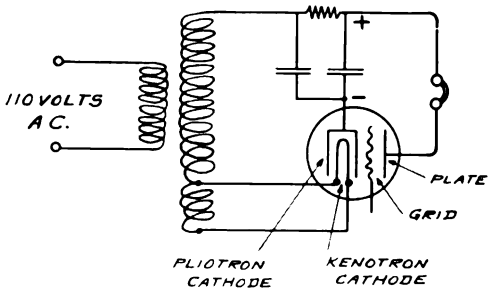

FIGURE 2—The same circuit as Figure 1, with kenotron incorporated in the pliotron

3—CONSTRUCTION

The essential construction can be seen in Figure 2. The structural features of one form of tube are shown in Figure 3. The filament is a helix of tungsten wire, maintained at approximately 2,300° K. by 2 amperes alternating current at 5 volts. At this temperature it has ample electron emission for its function as kenotron rectifier, and its radiation heats the surrounding cathode to a temperature at which it also has sufficient electron emission. The cathode is a nickel cylinder $\frac{1}{8}$ inch (0.32 cm.) in diameter by $1\frac{1}{8}$ inches (2.86 cm.) long, coated with barium oxide. Grid and plate are concentric cylinders surrounding the cathode, the grid being a helix 1 inch

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(2.54 cm.) long by ¼ inch (0.64 cm.) diameter, consisting of 40 turns of 3 mil (0.008 cm.) molybdenum wire.

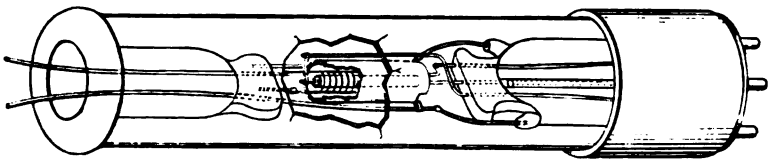

FIGURE 3—Drawing of a laboratory model of new tube

Figure 4 gives a cross-section view of a tube suitable for operation from a lamp socket, without transformers. The filament is a standard tungsten helix, such as is used in gas-filled tungsten lamps, and the cathode a nickel cylinder ½ inch (1.27 cm.) in diameter by 1½ inches (3.81 cm.) long.

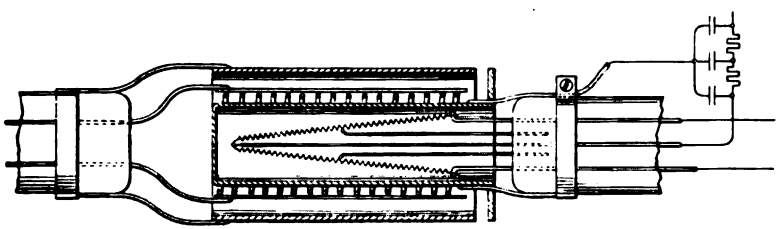

FIGURE 4—Cross-section drawing of a tube with 110-volt filament

4—CIRCUIT

A typical receiving circuit, using a single tube of the type shown in Figure 3, is sketched in Figure 5. Filament voltage is obtained from a small step-down transformer. One side of the 110-volt alternating current power line is connected to the filament, the other side to the plate terminal, so that the filament swings up and down ± 110 volts with respect to the plate terminal. On the negative swing it feeds current to the cathode, which current is stored by the first condenser, C_1, and further smoothed by the combined action of the second condenser, C_2, and resistance r.

Figure 6 shows a single tube with 110 volt filament acting as radio detector, using the alternating current power line as antenna. In this case the only accessory apparatus is the telephones, filter, and tuning unit.

5—RECTIFICATION

With a single tube used as half-wave rectifier, as shown in Figures 2 and 5, it is necessary that the outside surface of the

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cathode should have a higher electron emissivity than the inside in order that rectification may result. This may easily be accomplished by covering the outside of the cathode with an oxide

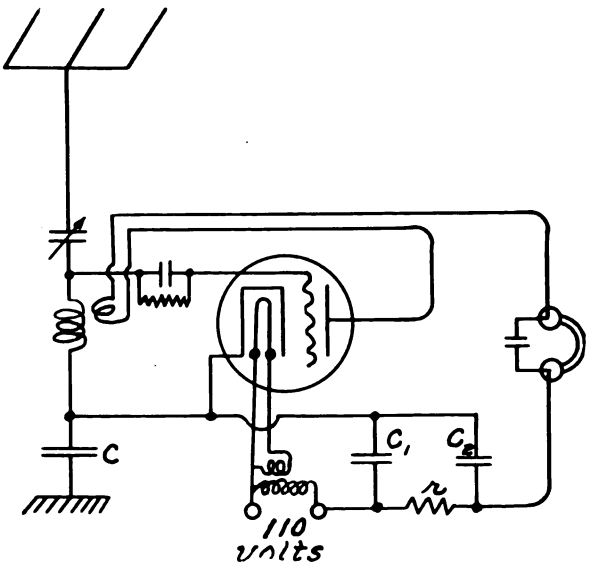

FIGURE 5—Simple receiving circuit, using new tube

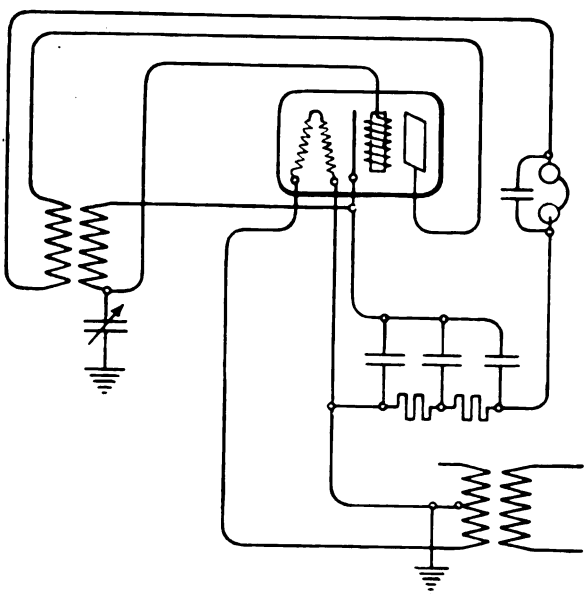

FIGURE 6—Receiving circuit for 110-volt tube, using power line as antenna

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coating. The necessity for unilateral electron emissivity is removed when full wave rectification is used. If a single tube with 110 volt filament is used a sfull-wave rectifier, as shown in Figure 4, the electron emission from the inside of the cathode may be the same as from the outside, provided it is less than that of the filament. For in this case the cathode is always receiving electrons from one end of the filament at the same time that it is emitting them to the other end, and it is only necessary that the number received should be in excess.

6—Filter

A resistance-capacity filter gives satisfactory operation, and is lighter and cheaper than the usual inductance-capacity filter. The filter shown diagrammatically in Figure 6, which consists of three 2-microfarad condensers and two 4,000-ohm resistances, is capable of furnishing 5 milliamperes at 60 volts with half-wave rectification. A ground connection is generally not necessary, as the alternating current line is sufficiently grounded. No harm can be done, however, by grounding the circuit at any point, except as it may interfere with operation or introduce alternating current hum. It is preferable to ground thru a condenser, as shown in Figure 5.

7—Characteristics

The volt-ampere characteristics of a tube similar to that sketched in Figure 3 are shown in Figures 7 and 8. For comparison, the characteristics of a standard UV-201 amplifier tube, at the same plate voltage, are shown on the same plot. It will be noted that the characteristics of the new tube are much steeper than those of the UV-201, as might be expected from its large cathode area and equipotential surface. The values of mutual conductance, plate resistance, and amplification constant for the equipotential-cathode tube shown are 1.50×10^{-3}, 18,000, and 27, respectively, as compared with 0.28, 20,000, and 6.0 for the UV-201. It will also be noted that the grid current characteristic is much steeper than that of the UV-201, so that a higher detection co-efficient may be expected.

8—Operation

The tube here described is in an ordinary pliotron in every respect except the method of supplying power to the plate and cathode. Hence its operating characteristics are identical with those of standard pliotrons, and the only points of interest are

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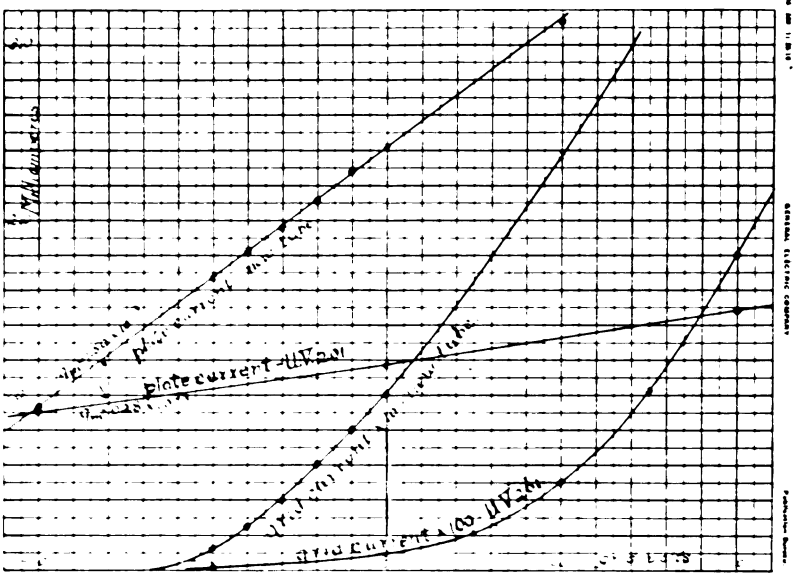

FIGURE 7.—Static characteristics of new tube and UV-201

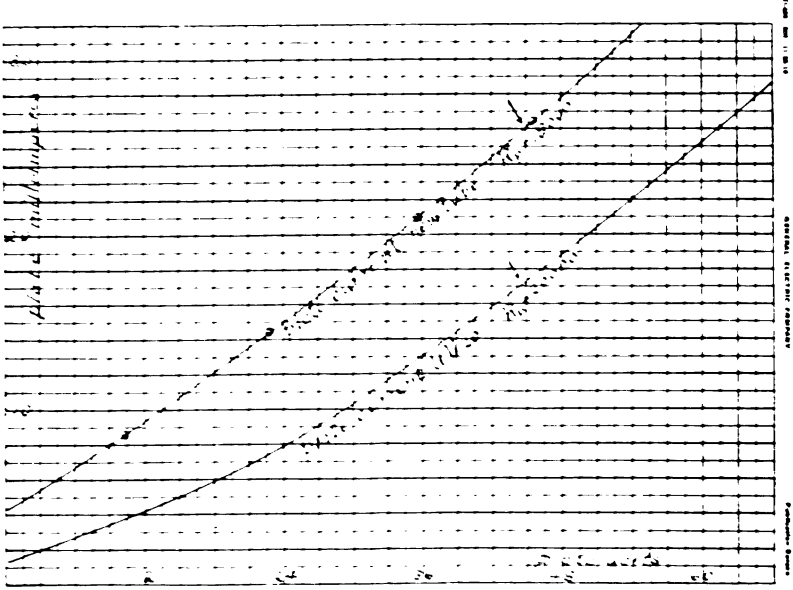

FIGURE 8.—Plate-resistance characteristics of new tube and UV-201

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the degree of amplification and detection, and the amount of alternating current hum introduced by the 60-cycle current.

The voltage amplification per tube is about four times that of the UV-201, at both radio and audio frequencies. This is especially significant in the case of radio frequency. At 300 meters, a resistance coupled UV-201 amplifier gives a voltage amplification of 2.0 per tube. The equipotential cathode tubes that have been measured average 7-fold voltage amplification with resistance coupling. A single tube is thus nearly the equivalent of 3 UV-201 tubes.

Under normal circuit conditions alternating current hum cannot be heard when a single tube is used as amplifier or detector. With two tubes in series, the hum can be heard only when the telephones are pressed tightly on the head. With three tubes in series the hum is quite noticeable, but not objectionable. A large part of this hum is probably due to circuit induction, and can be eliminated by shielding.

An important operating feature of this type of receiving equipment is its safety. Nothing that the operator can do can harm either himself, the receiving tube, or the lighting circuit. The alternating current power terminals are made inaccessible by the use of standard lamp receptacles and plugs, and all exposed terminals are protected by high resistances. No injury can be done to the tube by short-circuiting either the pliotron or the kenotron part.

9—Comparison With Other Methods

The only other method that has been tried for receiving with alternating current power is the use of standard pliotrons with a mid-point connection to the filament transformer. Plate voltage is furnished by kenotrons and filter. With symmetrical tubes and a perfectly linear plate current-grid voltage characteristic, this method should be applicable to audio frequency amplification without alternating current disturbance. Under practical conditions, even with a very high impedance load in the plate circuit, the hum is considerable. Under the very best conditions it is many times louder than in the equipotential cathode tubes. For radio frequency amplification this method would be satisfactory if such amplification were large enough to be of interest. For radio detection, either with or without grid condenser, this method cannot be used at all.

Research Laboratory,
General Electric Company.

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SUMMARY: A new type of four-element tube is described, which combines the functions of kenotron rectifier and pliotron, and can be operated from an alternating current source of power without either "A" or "B" battery.

The cathode is an equipotential surface so that alternating current hum is inappreciable even with three stages in series.

The combination of equipotential cathode and large cathode area results in unusually high amplification and detection constants, making the tube a practical radio-frequency amplifier.

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A NEW NON-INTERFERING DETECTOR*

By

Harold P. Donle

(Chief Engineer, Connecticut Telephone and Electric Company, Meriden, Connecticut)

One of the least efficient elements of modern radio is, despite the large amount of development since coherer days, the detecting system. Our best detectors are insensitive things when compared to galvanometers or telephones, and there appears room for considerable advance in increasing detector effectiveness. The present paper describes a radically new way of securing dependable detectors having high sensitiveness, which, it is hoped, will be considered to mark a step forward.

The ordinary three-element tube as a simple detector is not nearly sensitive enough to satisfy the present demands. Many attempts have been made to increase this sensitivity by including within the tube a gaseous atmosphere and while extremely effective detectors have been thus produced, they have required very delicate adjustment and in the majority of cases were not stable and required constant attention. Furthermore, it has been found practically impossible to reproduce in quantity tubes of uniformly maximum sensitivity.

The three-element electron tube and regenerative circuit is largely used at present for reception of radio signals. While it gives excellent results and certainly far exceeds in response any other method disclosed to date, nevertheless it has certain disadvantages and its widespread use has created a situation which is bound to retard the popular use of radio.

By using the three-element detector in a regenerative circuit greatly increased sensitivity is secured, but if regeneration is carried far enough to give worth-while response, there is produced considerable signal distortion. Furthermore, adjustments are critical, the slightest variation in capacity destroying the operating adjustment. What is still more important, the radiation

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from many regenerative circuits, particularly in the hands of inexperienced operators, creates an alarming amount of interference which if continued will seriously hamper reception of the present broadcasting programs.

There seems to be a definite need for a receiving tube which under no condition can radiate any energy from the antenna to produce interference, which can be easily adjusted, which is not affected by the body capacity while the circuit is being tuned, and yet which secures all this at no sacrifice of sensitivity and loudness of response.

For several years we have conducted experiments on many different forms of detectors, and particularly upon detectors employing ionization of metallic atoms. This was a most promising field of development since such ionization was found to be readily controlled and stable. As one of the results of this work we have developed the present tube which is the logical result of experimental work which we have done along these lines. This new tube has none of the disadvantages of regenerative and gaseous detector systems above mentioned. Its method of operation seems to involve many interesting phenomena, which are radically different from those occurring in other tubes.

The construction of one form of this tube is illustrated diagrammatically in Figure 1 where *F* is the filament, *A* is the anode, which may be of metallic sodium in the bottom of the tube, and *H* is the heater which is a short length of resistance wire cemented to the outside of the glass directly underneath the anode. This heater maintains the anode at proper operating temperature. *C* is the "collector" electrode of sheet metal bent

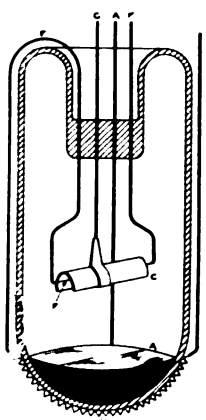

FIGURE 1

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into a "U" and positioned above the filament with its open side toward the anode.

Figure 2 shows these various parts before assembly and Figure 3 a finished tube.

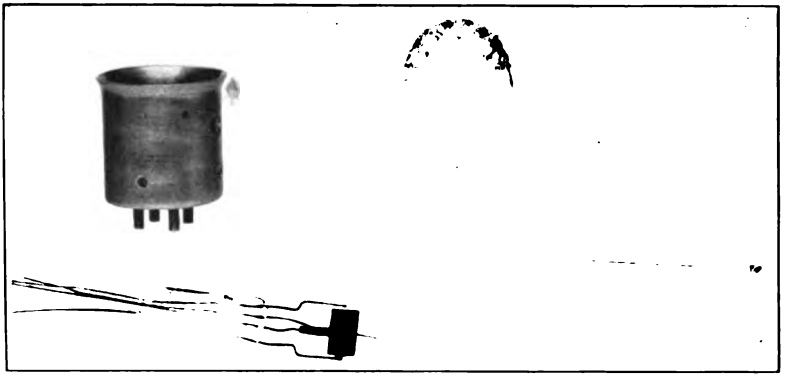

FIGURE 2

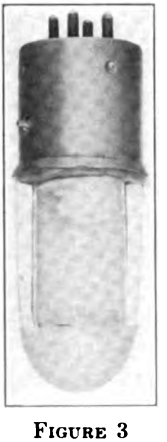

FIGURE 3

In operation the tube may be connected to the circuit, shown in Figure 4, which is simply a two-circuit tuner with one terminal of the secondary connected to the collector electrode of the tube and the other to a contact operating on a resistance connected directly across the filament battery terminals. The remainder of the circuit is as used with any simple detector.

The adjustment of collector potential is the only one necessary for efficient operation other than the usual variation of

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capacity and coupling of the tuning circuit. The potential of the "B" battery is not at all critical and usually may be varied between ten and thirty volts without much effect on response.

As a detector this tube is remarkably sensitive, its adjustment is simple, and it is absolutely stable in operation. This extreme sensitivity is readily reproducible and permanent.

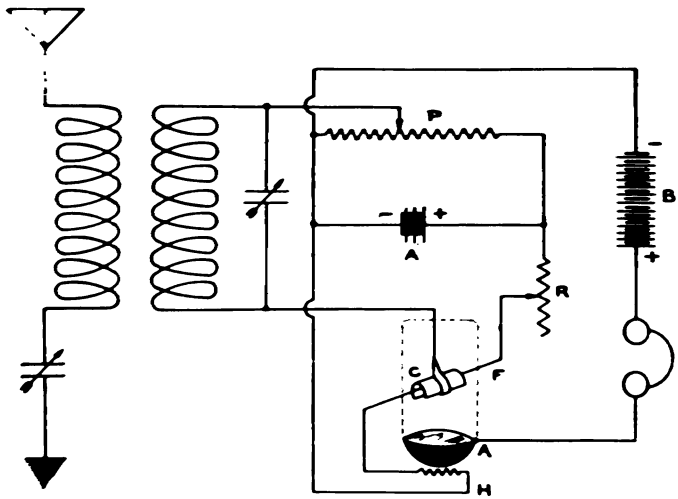

FIGURE 4

The response secured with this tube in a plain circuit equals in magnitude the response from a regenerator, using maximum non-oscillating regeneration. A regenerative circuit under this condition of critical adjustment will give very considerable distortion, which is particularly objectionable when receiving voice or music and which can only be eliminated by a reduction of regeneration and consequent reduction of signal strength.

On the other hand, the new detector creates no noticeable distortion, and, as it does not oscillate over its useful range, it cannot create any interference with other receivers. Furthermore, it is unaffected by small capacity changes, such as those produced by the operator's hand in tuning.

The response of the tube is greatly improved by very weak coupling between the circuits. This is due to its very low input impedance which also makes the proportion of capacity and inductance of secondary circuit for maximum results quite different from those for other tubes. Altho the new detector can be used successfully in an ordinary two-circuit tuner, results will

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fall short of the maximum unless means are available for selecting the best value of secondary inductance.

In this tube there is an electron flow from the filament to the collector, the magnitude of this current being due in part to the relatively large area of the collector and to its close proximity to the filament. It, therefore, receives an equivalent of large electron flow when it is at the same potential as the negative end of the filament. In order to reduce this flow an opposing potential (which may be taken from the "A" battery) is introduced into the circuit between collector and filament. This potential is called the neutralizing potential and is used as abcissas of curves shown in Figure 5, which show the variation in anode and collector currents I_a and I_c with variation of neutralizing potential E_n, and also the collector current when the anode circuit is open I_c'. The curve labelled $I_c - I_c'$ is the difference between the collector current with the anode circuit completed and opened. This last curve is interesting in that it apparently takes into consideration various phenomena concerned in the operation, and its slope is practically a direct index of the merit of the tube as a detector.

These curves show some of the fundamental characteristics of the tube. The abrupt bend in the collector current at $E_n = -1.8$ is a point at which maximum detection would be expected to take place, according to the usual conception of detection as being due to rectification over a section of the characteristic slope where the rate of change is large. One would also gather from this curve that the effect of a signal impressed would be to increase the average value of the collector and anode currents. Altho some detection takes place on this part of the curve, in magnitude it is not comparable to that secured over the sensitive portion of the slope. The point of maximum sensitivity for these curves is at $E_n = -1.4$ volts, which is at a relatively flat portion of the collector current curve and considerably above the lower bend. Furthermore, a signal impressed on the collector circuit always gives a decrease in collector current regardless of whether the characteristic curve at the sensitive point is concave or convex, many examples of both types having been observed. It should also be noted that this point of maximum sensitivity occurs somewhat above the center of the $I_c - I_c'$ curve. Another point of interest in connection with these curves is the values at operating potentials of collector and anode currents, the collector current usually being two to four times that of the anode. Special attention should be given also to the large changes of

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current produced by small changes of neutralizing potential.

Figure 6 shows the collector and anode currents at various values of anode potential E_a, but is of little interest in the present discussion except to show the very slight variation in collector current and the slow slope of anode current as a function of anode voltage. Considerable amplification might be expected from a superficial examination of these two anode current curves, Figures 5 and 6. However, the tube is not in fact an amplifier, probably on account of the comparatively high input power required for operation. It nevertheless has a high so-called voltage amplification, which in some cases runs as high as 400.

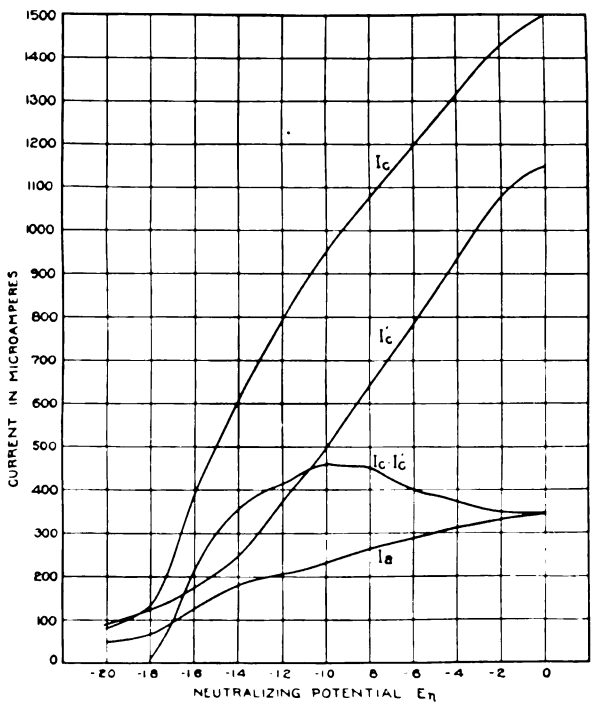

FIGURE 5

To determine some of the predominant features of the new tube in comparison with older types, a special tube was built, having filament and collector structure exactly as in Figure 1, but with the sodium anode replaced by a molybdenum plate. This special tube, like the usual new type, was evacuated to a high degree so as to preclude gas ionization. Since it contained no ionization metal, it operated on the pure electron basis. In

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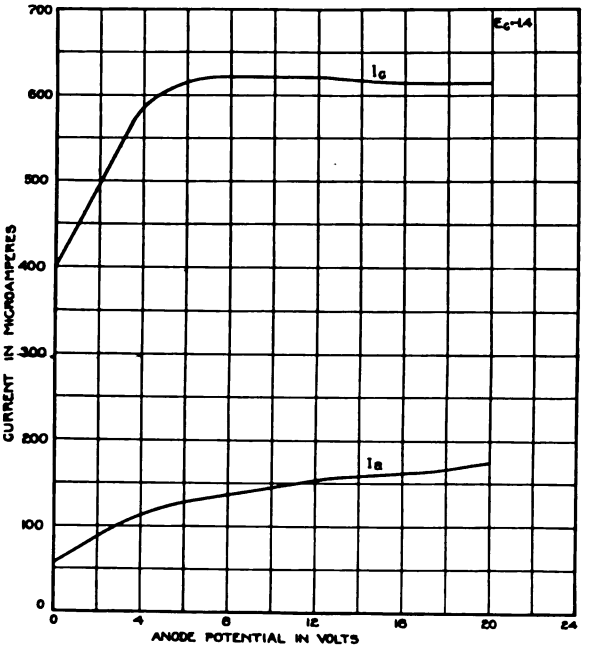

FIGURE 6

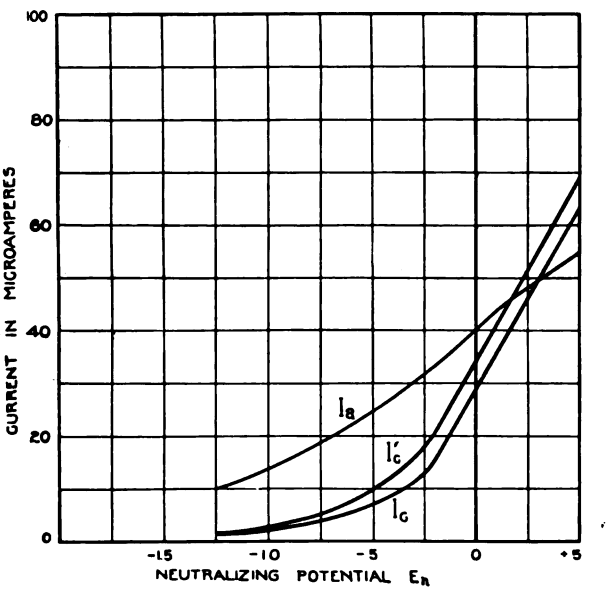

FIGURE 7

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the circuit of Figure 4 it showed none of the sensitive response which was had with the sodium tube. Characteristic curves for the special pure electron tube are shown in Figure 7; these were taken under conditions identical with those for curves of Figure 5. The effect of the new ionization phenomena on the form of these curves can be readily seen.

A most interesting point in comparison of these characteristic curves of Figures 5 and 7 is that in Figure 5 the collector current is increased by the completion of the anode circuit, while with Figure 7 the collector current decreases when the anode is connected, this last being similar to the effect on grid current when the anode circuit is opened in the ordinary three electrode tube. As shown in Figure 5, when the operating phenomena of the sodium tube are broken up by too high a neutralizing potential, we also secure the same result, that is, an increase in collector current when the anode is disconnected.

Figure 8 shows the change in collector current of the sodium tube for impressed signals of different wave lengths. The ordinates of this curve show in micro-amperes the actual decrease in collector current caused by a signal of variable frequency, but of constant amplitude. This curve shows that the response for the particular tube on which this data was taken becomes small above the wave length of 1,000 meters, and that below this wave length detection increases rapidly. This might seem to indicate a limited wave length band of operation for this type of tube, but the entire shape and position of this curve depends upon the relative potentials of the tube electrodes and upon their proportions and relative positions. It is possible radically to change this curve by a simple variation of the neutralizing potential. It is also possible by a proper selection of values to secure a serrated form of this curve of which Figure 9 is a typical example.

The possibilities indicated by this curve in the elimination of interference are obvious.

Figure 10 shows the variation in collector current at various values of E_n due to an impressed signal of constant frequency on the collector circuit. Thus it represents the range of the neutralizing potential for a signal, and gives some idea of the ease of adjustment of this variable for maximum signal. This adjustment is obviously broad and allows a relatively wide variation of neutralizing potential for an audible signal, making it simple and easy to locate the point of maximum sensitivity.

It might be of interest to state that the data for this curve was obtained while the tube was functioning on an antenna and

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that the ordinates represent the change in collector current produced by a signal from WOR (Newark, New Jersey) as received in Meriden, Connecticut, 100 miles (160 km.) away.

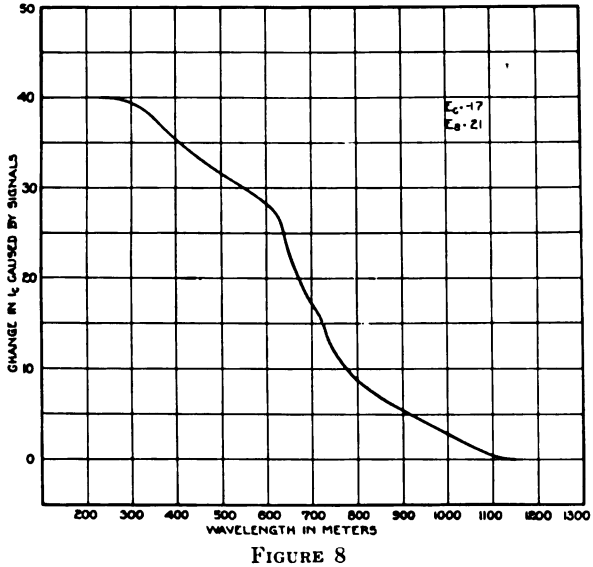

FIGURE 8

The effect shown in Figure 8 of signal frequency on response given by the tube, a most interesting phenomenon, is a consequence of a constant pulsation of collector current, the time period of which is controlled in part by relative electrode potentials and the position of the electrodes. This frequency of pulsation is low compared with the lowest frequency at which the tube is a sensitive detector. Furthermore, this pulsation of collector current at low radio frequencies is in no way affected by a capacity-inductance circuit associated with the tube. For example, if the collector electrode is connected directly to the contact on the potentiometer, with no periodic circuit interposed, the circuit will oscillate at a low radio frequency, the value of which is determined by the various factors set forth as above. Furthermore, when the tube is oscillating at a particular frequency, inserting a closed capacity-inductance circuit in series with the collector will have little effect on the oscillation of the tube.

The fundamental frequency of collector current pulsation for curve of Figure 8 was 74,300 cycles per second and it was possible to detect by use of an amplifier the first and second har-

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monics, both of which were obviously at frequencies well below the sensitive range.

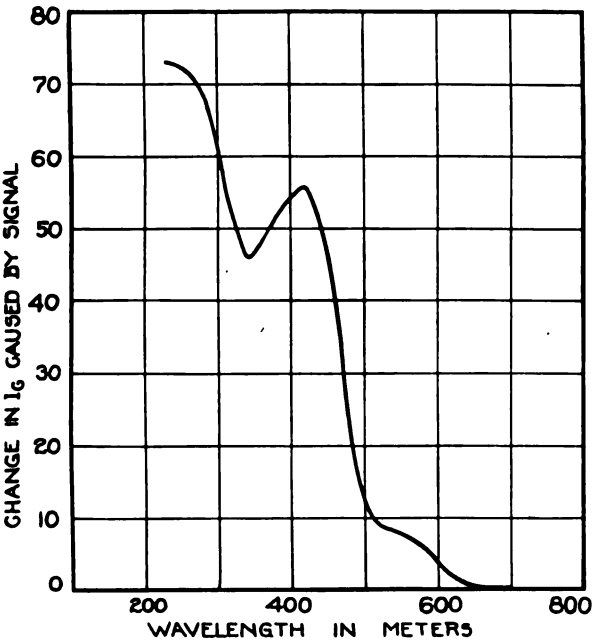

FIGURE 9

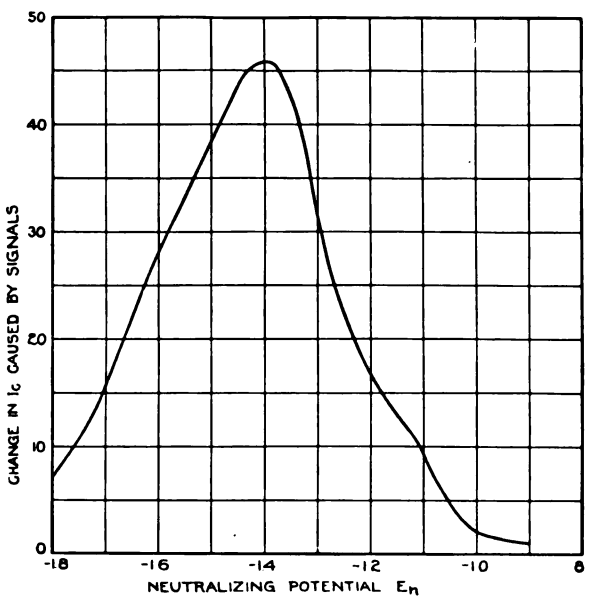

FIGURE 10

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Altho the collector current pulsates at low frequencies, the tube is entirely ineffective as a heterodyne receiver due to the almost negligible detection at this frequency. As can be observed by an examination of Figure 8, no appreciable detection takes place until the signal frequency is at least four or five times the fundamental pulsation frequency.

The fact that the collector current pulsates and that this pulsation is not affected by a capacity-inductance circuit demonstrates that there is within the tube a mechanism, necessarily connected with ionization, which causes an alternate build-up and break of current in the collector circuit.

When the alternating potential of a signal is applied to the collector circuit, the pulsation is impeded to a greater or less extent depending upon the amplitude and frequency of this potential. Furthermore, since the pulsation causes a build-up of average collector current, the effect of a signal in this circuit is invariably to reduce the average value of this current.

Since slow changes in the collector circuit current are reflected in the anode circuit, a decrease of the average value of the collector current will result in a like decrease in the anode current, but this occurs without any appreciable amplification. By experiment on large number of tubes the ratio of change of power in collector circuit to resulting power change in anode circuit was found to be approximately unity.

This lack of amplification accompanying the detection effects, makes it feasible to operate the tube with an indicating device, such as a telephone receiver, placed directly in the collector circuit instead of in the anode circuit as shown in Figure 4. This is of interest, altho results are not quite as good as with the normal circuit (Figure 4), due to the fact that in the low impedance circuit, the high resistance of the receivers interferes with proper functioning. The anode circuit impedance is well suited to the standard telephones and transformers on the market.

With the telephones in the collector circuit the device might seem to be more or less the equivalent of a two-element tube, but the contrary is true, however, for with this connection, if the anode circuit is opened, no operation whatever will be secured, thus demonstrating that satisfactory operation depends upon the presence of this new anode circuit.

The action of this tube depends upon ionization produced by electrons emitted from the filament. It is, however, not the purpose of this brief paper to go into detail beyond a description of some of the most interesting characteristics.

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The use of an easily vaporized anode metal allows great possibilities in the way of controlling ionization, in part because it becomes possible to secure a very sharp density gradient of atoms available for ionization, and to supply these atoms continuously at the proper rate required for operation, thus leaving unrestricted the mean free path beyond the zones of ionization.

Sodium is a convenient metal of this type, but similar useful effects have already been secured from a variety of differently composed anode materials. The present paper describes only one of the structures used with the sodium anode in this tube, the supply of atoms being regulated by the temperature of the anode and this varied by the external heater. In practice the heater is connected in series with the filament, and the two are thus controlled simultaneously.

At first thought it would seem necessary to allow a considerable time after lighting the tube filament before the anode would become sufficiently hot. That is, however, not the case on account of the following most interesting phenomenon. When the filament is first lighted the anode receives a small amount of heat by direct radiation from the filament and there will be, even at this relatively low temperature, a considerable emission of particles from this anode. This emission will, however, decay with time, and in a period of possibly one hour it will have reached a small fraction of its initial value. However, with the external heater connected in series with the filament, as described above, when the filament is lighted the anode will commence to receive heat from this heater. Its effect in raising the anode temperature will be necessarily slow on account of the interposition of the glass wall of the tube, but the temperature of the anode will be increased by this heater at a rate approximately correct to compensate for the decay of the initial emission, and thus the emission of particles from the anode will become fairly constant within a few seconds after the tube is first lighted. The result of this combination of affairs is that when the tube is lighted it is almost immediately in operative condition, altho in some cases a slight re-adjustment of neutralizing potential is later necessary to maintain a maximum sensitivity.

Ionization controlled in this way is extremely stable and these tubes may be maintained in their most sensitive adjustment for long periods of time. This is an impossibility with a gaseous detector. Also, with this type of ionization, it is possible to manufacture in quantity tubes with little if any variation of

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sensitivity. The tubes will remain substantially constant in sensitiveness thruout their life.

It is felt that the unique characteristics of this device and its inherent advantages over prior detectors should offer a new avenue of approach to the problem of detection. By replacing, without loss of sensitiveness, many of the regenerators now in use the new tube should further help to eliminate much of the present disagreeable interference.

Research Laboratory of
the Connecticut Telephone and Electric Company,
Meriden, Connecticut,
November 8, 1922.

SUMMARY: A new detector of high sensitivity is described which to the stimuli of weak impulses gives a response at least equal to a regenerator with the most critical regeneration. This high sensitivity is secured with the use of metallic ionization and a new electrode termed the "collector." Ionization of this type is readily controlled and stable and makes it possible to secure uniform characteristics on production tubes.

Static characteristics are given and show some points of particular interest such as, for example, the high value of current to collector as compared with the anode current. Curves are also given showing the effect of frequency on response, indicating great possibilities in the elimination of interference. The effect of a signal is shown to always decrease the steady value of the collector and anode currents irrespective of the shape of the characteristic curve.

As this detector does not oscillate thruout its sensitive range it obviously cannot radiate any energy and, therefore, interfere with broadcast reception by neighboring receivers.

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A HIGH VOLTAGE MECHANICAL RECTIFIER*

By

S. T. Woodhull

Engineering Manager, (American Radio and Research Corporation' Medford Hillside, Massachusetts)

The conventional type of direct current generator of small power is limited to about 1,000 volts per commutator, because of the difficulty of insulating the commutator segments and armature windings in the small space. In generators for operation of radio transmitting equipment, insulation troubles are more pronounced because of the possibility of radio frequency surges getting back into the winding. The voltages of these surges are not equally distributed thruout the winding, but builds up in the first few turns of the armature coils. Altho surge voltages in themselves seldom exceed twice normal voltage, the voltage will subject the outer turns of the coil to many times normal voltage.

Many devices are in service to provide a generator for direct current, such as thermionic tubes, gaseous conduction, mechanical rectifiers and, of course, many well-insulated, direct-current generators of the conventional type.

The purpose of this paper is to describe a direct-current generator of the mechanical rectifier type, using transformer action for the generation of the high voltage and a synchronous commutator for its rectification.

The generating equipment comprises a polyphase alternating current generator with an extension shaft, on which is mounted the rectifying commutator, having segments corresponding to the phases of the generator. A single phase transformer is provided for each phase for stepping up the voltage before rectification. In practice nine phases are found suitable for transmitter operation.

The schematic wiring diagram (Figure 1) shows the connections for a two-pole, three-phase machine. *A* represents the generator, *B* the single-phase transformer, and *C* the commutator segments. Slip rings *D* are provided for collecting the direct current.

* Received by the Editor, December 1, 1922.

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It will be noticed in this circuit that, differing from the common type of mechanical rectifiers, the secondaries of the transformers are connected in series. The commutator segments are shown displaced 120 degrees to correspond to the phase rotation of the generator. The series connection of the transformer in a nine-phase machine reduces the voltage commutated per pair of brushes to approximately 25 per cent. of line voltage. This connection, therefore, very naturally reduces commutator insulation. The ripple of the delivered current is the same as that encountered in commutating line voltage per pair of brushes, which is approximately 5 per cent. of delivered voltage.

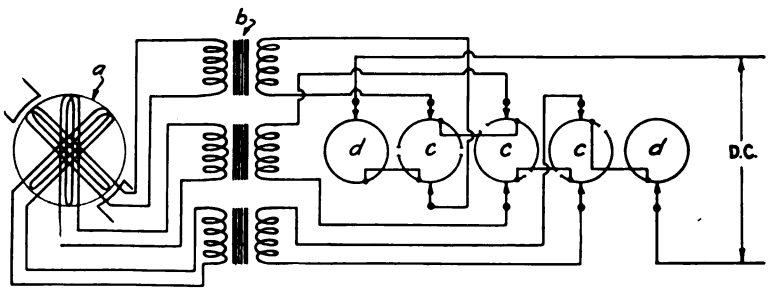

FIGURE 1

The generator should be wound with one slot per phase per pole in order to provide a wave having a long zero potential, so that the point oi commutation is not critical. Since the point of commutation depends upon the power factor, the generator synchronous impedance should be as small as possible.

The transformer design is of the closed core type, having a primary and secondary winding on each leg. Switching mechanism can be provided for throwing the secondaries in series or parallel to give wide variation of voltage. Following the same design as the generator, the leakage of the transformer should be kept to a minimum. Insulation of the transformers should be suitable for full line potential, both between primary and secondary and secondary and core. It is preferable to double space the first few turns of the secondary winding to more equally distribute surge potentials.

The commutator offers most of the difficulties in design. It is best solved by the use of an air brake type in which all insulating materials are kept from the commutation surface. The commutator segments may be cast and turned true after assembly. Insulation between segments is provided by discs of

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smaller diameter than the commutator segments. These discs also insulate the segments from the shaft. The brushes must, of course, be wide enough to span the break, so that the circuit is continuous. The sparking which accompanies this type of commutator can be decreased to a negligible amount by the addition of a one microfarad condenser across each pair of brushes. Provision is made for rotating the brushes with respect to the commutator to find the best point of commutation. Since the zero potential point changes with load, it is necessary to adjust this for each change in load. In machines of small power, that is, of 0.5 kilowatt capacity or less, the commutator may be adjusted for full load without injurious effects of sparking at no-load.

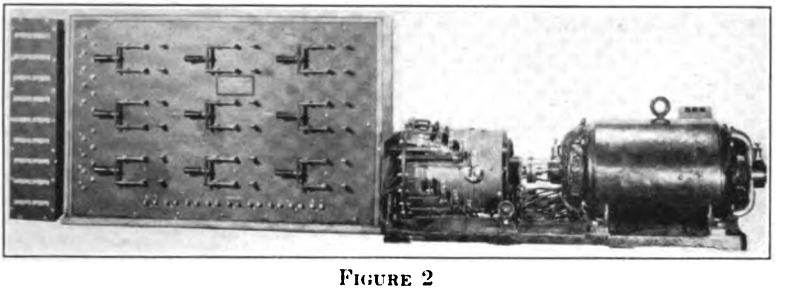

FIGURE 2

Figure 2 illustrates the general form of a 0.5 kilowatt, 20.000-volt generator. The generator proper is nine-phase, four-pole, 1,800 revolutions per minute. Nine single phase transformers are mounted in the cabinet. The double-pole, double-throw switches on the front of the cabinet throw the secondaries in series or parallel. The addition of a field rheostat for the generator provides a range of voltage from 5,000 to 20,000. Because of the size of the commutator required for this voltage, separate mountings are necessary.

The advantage of a machine of this type is in its ease of insulation. The high voltage is limited to the transformer and commutator, both of which can be readily designed.

SUMMARY: A mechanical power rectifier for high voltage direct current production is described, and its design and operation discussed.

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RADIO TRANSMISSION MEASUREMENTS*

By

Ralph Bown

(American Telephone and Telegraph Company, New York)

Carl R. Englund and H. T. Friis

(Western Electric Company, New York)

Almost from the beginning of the radio art there has been sought a suitable way of measuring and expressing the strength of received signals and the effect of static on their readability. It is not until very recent years, however, that any really effective progress directed toward this goal has been made. This has been not so much due to any lack of diligence on the part of radio engineers as to a lack of adequate experimental tools. In recent months the technical press has reflected an increasing and world-wide interest in this subject. Our paper, as is indicated by its title, deals with such experimental measurements, but before going into the details of apparatus and methods we wish to give a few paragraphs to the fundamental background against which the subject should be viewed. For this reason we have started our presentation below with a very brief transmission analysis of the generalized radio "circuit" or system. Following this analysis there are given brief descriptions of the methods and apparatus which we have been developing in the last two years for measuring experimentally two things of fundamental importance, namely—absolute values of the electric field strength of radio waves and effective values of radio noise. To give the descriptions greater interest and to demonstrate the practicability of the methods and apparatus, illustrative results have been included showing cases where the apparatus has already been successfully used to advantage. These results are given, however, only as illustrations and no attempt is made to adequately discuss them as results. It is hoped that this may be done in later papers.

* Received by the Editor, March 9, 1923. Presented before The Institute of Radio Engineers, New York, March 21, 1923.

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Transmission Analysis of Radio Circuit

A radio system viewed from the transmission standpoint splits naturally into three distinct parts as indicated in Figure 1. First is the transmitting end of the system in which the radio frequency signal power is produced and radiated. Second is the

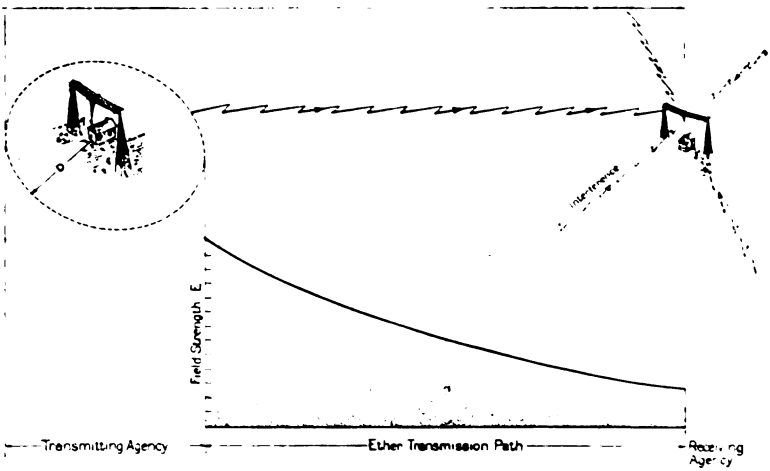

Figure 1—Transmission Analysis of Radio Circuit

ether transmission path, and third is the receiving antenna and its associated receiving apparatus. In all three of these portions the signal-bearing currents or waves are subject to losses. In the first, and usually the third, they receive gains due to some form of amplification. The radio transmission engineer must so distribute the gains in the system that the minimum cost and the desired service efficiency are achieved. The gains are produced in terminal apparatus while the losses occur in the transmitting and receiving antenna structures and in the ether path between them. Before the transmitting and receiving apparatus can be chosen to give the most suitable partitioning of the gain, the losses must be isolated and evaluated. It is with this part of the problem that the present paper is concerned.

In the transmitting end of the system the important element from the present standpoint is the radiation efficiency of the transmitting antenna structure. This efficiency is defined as the ratio between power input to the antenna and power actually radiated, expressed as a percentage. The input is readily determined as the product of the total antenna resistance and the square of the antenna current, both of which may be

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measured by well known methods. The radiated power is the product of the radiation resistance and the square of the antenna current. The radiation resistance is in accordance with the usual theory,

$R = 1600 \frac{h^2}{\lambda^2}$ ohms where h and λ are in the same units. The wave length being known, it remains to determine the effective height h. Now

$h = \frac{E \lambda d}{377 I}$ meters, where λ and I are the sending wave length and antenna current respectively in kilometers and amperes, and E is the effective or root mean square value of the electric field strength of the radiated waves in micro-volts per meter at a distance d kilometers from the antenna. All of these quantities are readily found except the field strength E. If E is measured, all the data are available for figuring out h and the radiated power.

It is worth while to consider some of the assumptions this method of evaluating the radiated power involves. It assumes first of all that the antenna has no directional effect. This is not usually the case and unless interest is confined to one direction, measurements of E must be made in a number of directions and the results properly averaged. It assumes also that the field surrounding the antenna is the ideal one for which the formula is derived. This assumption is probably a safe one if the distance d is sufficiently large. Another assumption is that all losses occurring between the antenna and the point at which E is measured are antenna losses. This is really a matter of definition and it is, at least for present purposes, quite reasonable to consider as transmitting station losses those occurring out to the point where the waves have gotten well started on their way. E must be measured not closer than several wave lengths from the antenna to have these conditions obtain.

For a knowledge of the performance of the ether transmission portion of the system, measurements of E, the electric field intensity of the waves, are needed at a number of places along their route of travel beginning at a point suitably near the transmitting station as discussed above and continuing to the receiving station.

At the receiving station, which forms the third portion of the system, another factor enters into consideration. Interfering electric waves from static, other stations, local electric power systems and so on, are usually present and the incoming

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signal must be of sufficient strength to dominate them satisfactorily. With a simple form of receiving antenna, the antenna efficiency is important only in determining the amount of amplification required in the receiving set since the antenna picks up both signal and noise in a ratio which is determined by their relative strength as ether waves. At the receiving station it would thus seem to be possible to state the minimum field strength of signal required for satisfactory operation, in terms of absolute strength of the radio noise field. It must be borne in mind, however, that the antenna and receiving set are in general designed to reduce radio noise without detriment to signal, by means of selectivity, directional effects and the like, so that the minimum permissible absolute value of signal depends also on the nature of the receiving system.

To bring the engineering aspects of the whole subject more clearly into view let us consider the information which would need to be available to enable a radio engineer to predict with certainty the cost of obtaining a given grade of service from a large and important radio project. This needed information may be itemized as follows:

1. A statement of the grade of service desired.
2. The relation between the cost of various sizes of transmitting apparatus and their power outputs into the antenna.
3. The relation between cost and radiation efficiency for various sizes and types of transmitting antenna.
4. Statistical data on the ether transmission efficiency from transmitting station site to receiving station site.
5. Statistical data on the absolute volume of radio noise at the receiving station site.
6. The relation between the cost and noise reducing capabilities of various receiving antenna and apparatus.

Radio engineering will have become pretty well standardized when a project may be estimated with all this information in hand. However, the respects in which present knowledge fails to meet the list are an indication of the lines along which progress is needed. It is interesting to note that in all but the first two of these items experimental measurements of radio field strengths and of radio noise would be basically useful in getting the desired information in quantitative form.

Method for Measurement of Radio Field Strengths

Fundamentally the measurement of radio field strength is

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simplicity itself. All it requires is the measurement of received current in an antenna of known constants. The difficulties come in knowing the constants and measuring the minute currents produced by weak signals.

In many cases the ordinary open antenna has been used. It has the advantage of collecting relatively large amounts of power and making the current-measuring problem easier. We have, however, preferred the loop antenna as more stable, portable, and easily and accurately calibrated.

Where the fields to be measured are strong, as near the transmitting station, it is possible to measure the current in the receiving antenna directly by means of a thermal instrument or a vacuum tube voltmeter. In the general case this is not so, and a comparison method must be resorted to. A local oscillator manufactures a small amount of radio frequency power of the same frequency as that of the signal to be measured. This is fed into the receiving antenna in a known and adjustable amount. A receiving set also connected to the antenna is used as an indicator to tell when the currents produced in the antenna by the distant and local sources are equal. Where the transmitting station is co-operating and under control or where it is sending a certain type of signals such as time signals, the distant and local signals may be introduced separately and alternately and their effects on the receiving set compared aurally or by means of an indicating instrument if static conditions permit. When the transmitting station is not co-operating, the use of a loop antenna permits it to be cut out when the local signal is introduced, by turning the loop 90° to the directional blind spot. If static permits, the antenna may be cut off entirely and the comparison made directly against the local source feeding into the receiving set. This latter method cannot be followed where the comparison is aural and radio noise is present, because the ear cannot properly match two tones only one of which is accompanied by noise.

Some European experimenters have used inductive coupling as the means of introducing the local signal into the antenna. For our work we have selected a resistance shunt method as being simpler and capable of easier calibration. The exact way in which this shunt is related to the antenna circuit depends upon various factors important among which is the frequency being measured. In the description of measuring sets given below the matter is discussed more fully.

It will no doubt be appreciated that one of the most difficult

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experimental problems in the construction of a field strength measuring set is to keep the oscillator which produces the local signal power from affecting the antenna directly. The success of the method depends on having all the power fed to the antenna thru the circuits designed to meter and control it and on having no external "pick up." It is found that this requirement can be met sufficiently if the oscillator power is kept to the lowest workable value, the oscillator is given a reasonable separation from the antenna and the whole input circuit is carefully and systematically shielded.

Long Wave Field Strength Measurements

In a note published recently in the Proceedings,[1] Mr. Englund has described the initial form of our field strength measuring sets for very long waves. For completeness and as illustrative of the method in its simplest form it will be briefly reviewed here. The apparatus was designed to measure signals in the neighborhood of 23,500 cycles per second. From the diagram of Figure 2, it will be seen that it consists of three main parts, namely, the local signal input apparatus, the loop antenna, and the receiving set.

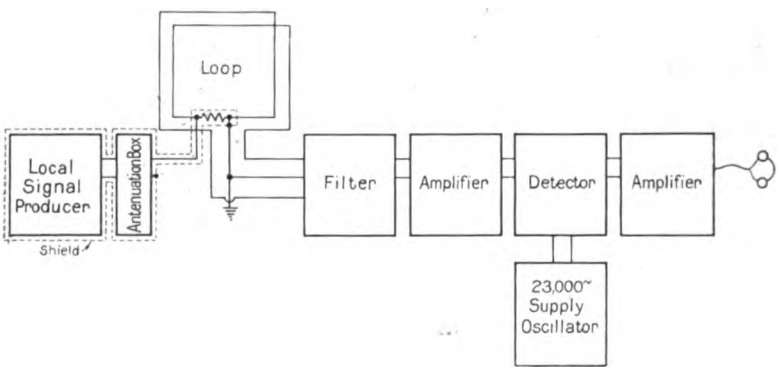

Figure 2—Simplified Diagram of Long Wave Field Strength Measuring Set No. 1

There is nothing out of the ordinary in the loop antenna and the receiving set except the use of a band filter between them to give very high selectivity. The input apparatus consists of an oscillator circuit complete with its own "A" and "B" batteries, which generates 23,500 cycle current. This current passes thru a thermocouple type of milliameter into a 600-ohm adjustable

[1] Proceedings of The Institute of Radio Engineers, volume 11, number 1, February, 1923, page 26.

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artificial line designed for radio frequency use. The output end feeds thru a 599-ohm resistance into a one-ohm resistance shunt which is included in the loop circuit. The whole input system is covered by a copper shield. This will be seen by reference to Figure 3 which is a photograph of a set up using this same input equipment. The large copper box at the extreme

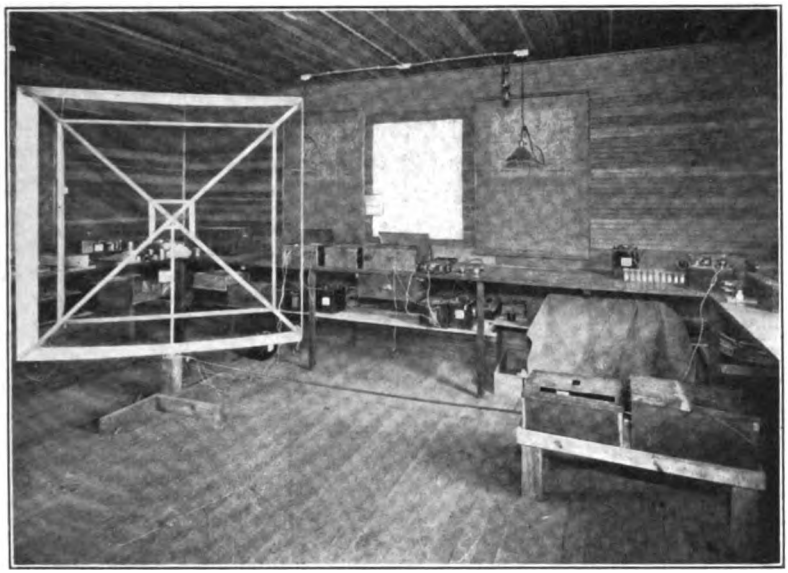

FIGURE 3—Long Wave Field Strength Measuring Set Showing Shielding of Local Signal Input System

right on the low bench contains the oscillator with its "A" and "B" batteries The next copper box, which is joined to the first by a short length of copper pipe, contains the thermocouple instrument, artificial line, and 599-ohm resistance From this box a copper pipe extends over to a small copper box on the loop base. This pipe contains the single wire leading to the one-ohm shunt in the copper box. The return circuit is thru the copper pipe.

The operation of the set when measuring signals from a co-operating transmitting station sending dashes separated by spaces is as follows. The loop is oriented to receive maximum signals. The signals are tuned in properly thru the filter and received as a tone by the aid of the heterodyne oscillator in the receiving set so that they may be listened to or, if static permits, read on a microammeter. The local signal oscillator is then turned on

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and its frequency adjusted to be exactly the same as that of the incoming signals. Then by means of a key the local signal is cut on and off during spaces in the incoming signals so that the two signals (incoming and local) are heard alternately. When the local signal oscillator is adjusted to the proper frequency the two will have the same tone pitch. It only remains then to adjust the local signal by means of the artificial line to have the same loudness as the incoming signal and to read the setting of the artificial line and the value of the current flowing into it.

Since the artificial line, when properly terminated, is a current attenuator, the current flowing into the line multiplied by the attenuation factor for which the line is set gives the much reduced current which flows out to the shunt in the loop circuit. A small portion of this current goes thru the loop itself, which forms a series resonance circuit in parallel with the shunt, so that the current thru the shunt is less than that coming from the artificial line by an amount equal to the ratio of the shunt and loop resistances. This ratio is usually too small to warrant the correction.

The shunt current in amperes multiplied by the shunt resistance in ohms (one ohm in this case) gives the voltage introduced into the loop, which is in turn equal to the voltage induced in the loop by the incoming signal waves. The voltage V induced in the loop by incoming waves, the effective field strength of which is E micro-volts per meter is

$$V = \frac{2}{3}\pi f A N E \times 10^{-18} \text{ volts}$$

where f = frequency in cycles per second, A = loop area in square centimeters, and N the number of turns. Substituting for V its value $V = I_L F R_s$, where I_L = current into the artificial line in amperes, F the current attenuation ratio setting of the line, and R_s the resistance of the shunt in ohms, we have

$$E = \frac{3 I_L F R_s}{2 \pi f A N} \times 10^{18} \text{ micro-volts per meter.}$$

It should be noted that this calculation requires no accurate knowledge of the loop resistance, inductance or capacity, since the measurement matches voltages directly and the resulting current is of no import. There is, to be sure, some error due to the fact that the incoming signal voltage is induced in a distributed manner and the local signal voltage is introduced at a fixed point in the circuit, but our calculations lead us to believe that this error is too small to warrant any correction.

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Setting up an outfit of this kind is fraught with many experimental difficulties which we unfortunately have not space to consider here in detail. The shielding must be effectively and carefully bonded into a continuous conducting sheath. Multiple grounds must be avoided. The final test is to short-circuit the shunt with a heavy copper conductor of substantially zero resistance and so to set the oscillator output and the attenuation box that a relatively large current flows thru this conductor. If the receiving set is then unable to detect a voltage in the loop which is appreciable in comparison with signals of the intensity which it it desired to measure, the set is free from spurious effects.

The second type of long wave measuring set which we have used was made up for measuring signals in London in connection with the recent transoceanic telephone experiments carried out by the American Telephone and Telegraph Company and the Radio Corporation of America in co-operation. The wave length is somewhat shorter (5,300 meters, 57,000 cycles), but the local signal input system is practically identical with that of the initial set except for the constants of the oscillator. A further difference is that a double detection type of receiving set was used. The entire outfit is diagrammed in Figure 4. The loop antenna has a very loose capacity coupling to a secondary circuit which feeds into the radio frequency detector. This detector also has impressed on its grid a 91,000 cycle voltage from the radio frequency beating oscillator. The incoming signal frequency is 57,000 cycles, so these two beating together produce 34,000 cycles in the detector output. This is selected by the filter circuit which permits the passage of a 2,000 cycle band from 33,500 to 35,500 cycles and greatly attenuates all other frequencies. The signal is then amplified to the desired degree and impressed on the audio frequency detector together with a 35,500 cycle voltage from the carrier supply oscillator. In case the incoming signal is the 57,000 pure continuous wave which is used for measurement transmission, it comes out as a 1,500 cycle tone in the telephone receivers. The operation of the outfit, except for the tuning of the receiving set, is exactly the same as with the simpler set. Rocky Point transmits dashes and in between these the local signal is turned on for matching of tone pitch and intensity.

In Figure 5 is shown the set up of the apparatus in London where it has been in use for the past few months measuring the special test signals from Rocky Point. At the left of the picture is the local signal input apparatus with the copper shielding

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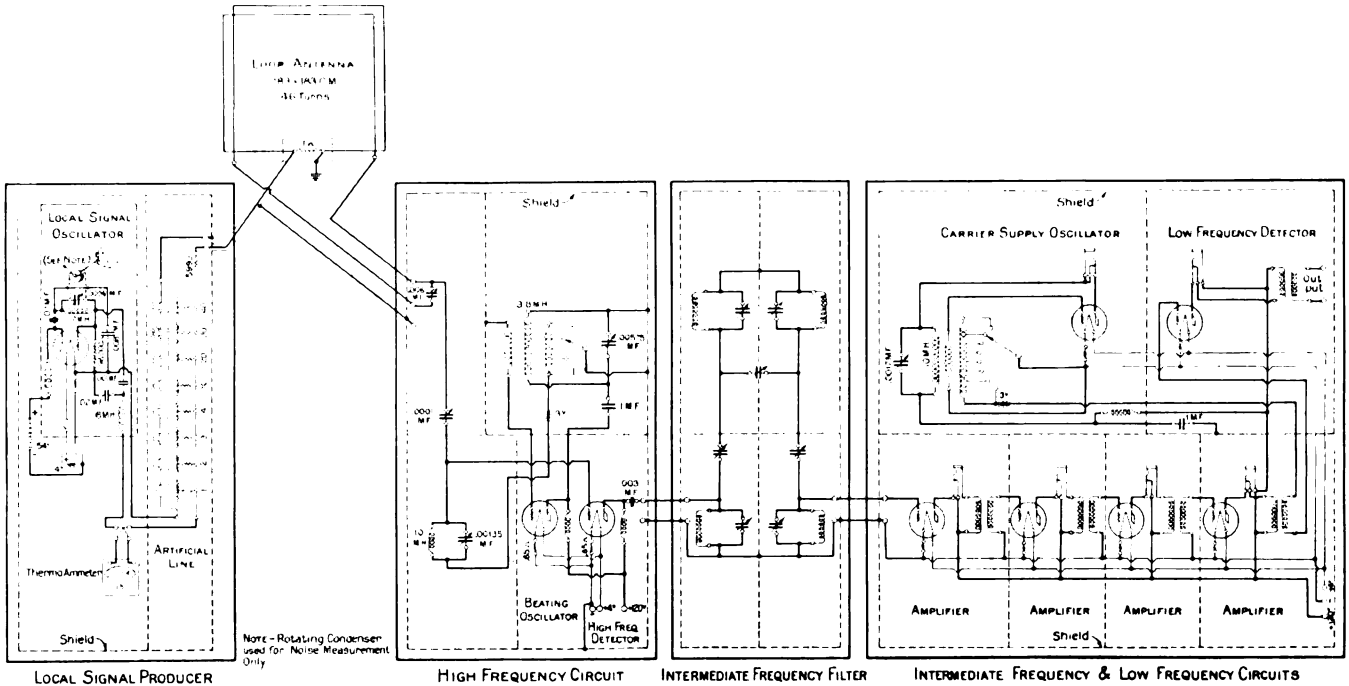

FIGURE 4—Long Wave Field Strength Measuring Set Number 2

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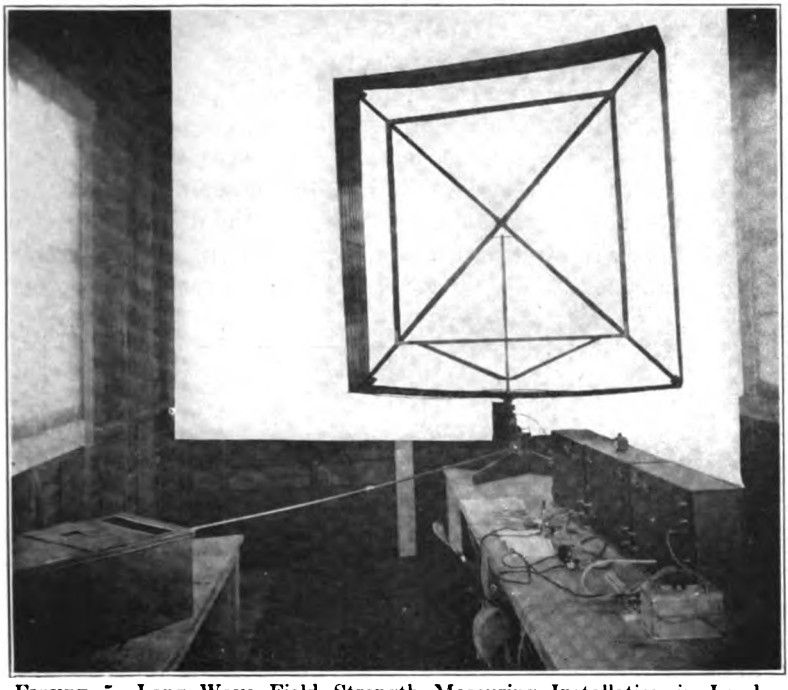

FIGURE 5—Long Wave Field Strength Measuring Installation in London

pipe leading from it to the loop. The three boxes on the bench contain the receiver portion of the measuring set. An illustrative example of the data being taken is given in Figure 6. This shows the hourly field strength readings made during a 52-hour run on February 11, 12, and 13, 1923. A considerable amount of such data is being obtained, but until the tests are completed any general discussion of the results would be premature. The method of interpreting the field strength curves in combination with noise measurements is taken up in later paragraphs.

SHORT WAVE FIELD STRENGTH MEASUREMENTS

In measuring short wave signals, as from radio broadcasting stations, it was anticipated that the direct method of comparing the voltage induced in the loop antenna by the incoming carrier wave with that introduced by a local oscillator at the same frequency would be difficult. The higher frequency makes the "pick up" from the local signal oscillator harder to reduce to satisfactory values. In getting around this trouble we employ a modified method devised by Mr. Friis which is believed to be

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entirely new. A detail circuit diagram of a measuring set of this type is shown as Figure 7.

The loop antenna is provided with a tuning condenser across its terminals in the usual way, but its central point is grounded and connection to the receiving set is from ground to one side of the loop. This is great measure preserves the directional balance of the loop and minimizes the damping due to the receiving set. The receiving set itself is of the double detection type and has intermediate frequency amplifying and selecting circuits designed for 45,000 cycles. As will be seen by reference

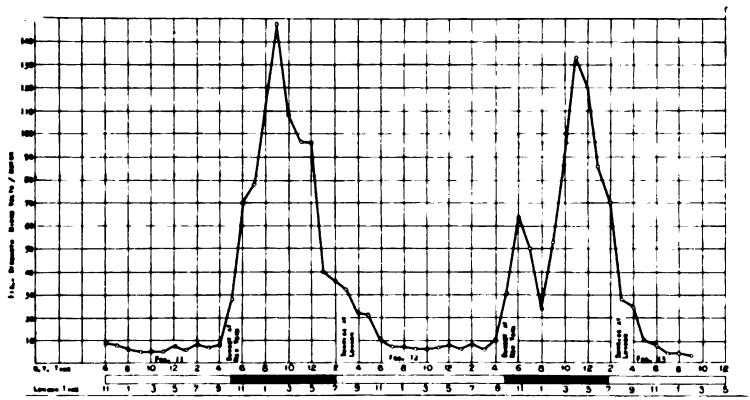

FIGURE 6—Field Strength Measurement. Transatlantic Signals from Rocky Point, Long Island, United States of America. Measured in London, England, (Distance 5,000 km.) (3,200 miles), February 11, 12, 13, 1923

to Figure 8, if the incoming signal has a frequency of 750,000 cycles, the loop is tuned to 750,000 cycles, but the radio frequency beating oscillator is set to produce a frequency of either 705,000 or 795,000 cycles, so that, beating with the 750,000 cycle signal in the radio frequency detector, it will produce the 45,000 cycles, necessary for further amplification and selection. The local signal oscillator is not set at 750,000 cycles, but at a frequency which is just 45,000 cycles the other side of the beating oscillator so that it also will produce 45,000 cycles at the output of the radio frequency detector. This means that if the beating oscillator is below the loop tune, at 705,000 cycles, the local signal oscillator will be 45,000 cycles still lower, or at 660,000 cycles. Or if the upper position has been selected, the two will be at 795,000 cycles and 840,000 cycles respectively. In either case, insofar as the intermediate frequency and audio frequency output circuits are concerned, the incoming and local signals are

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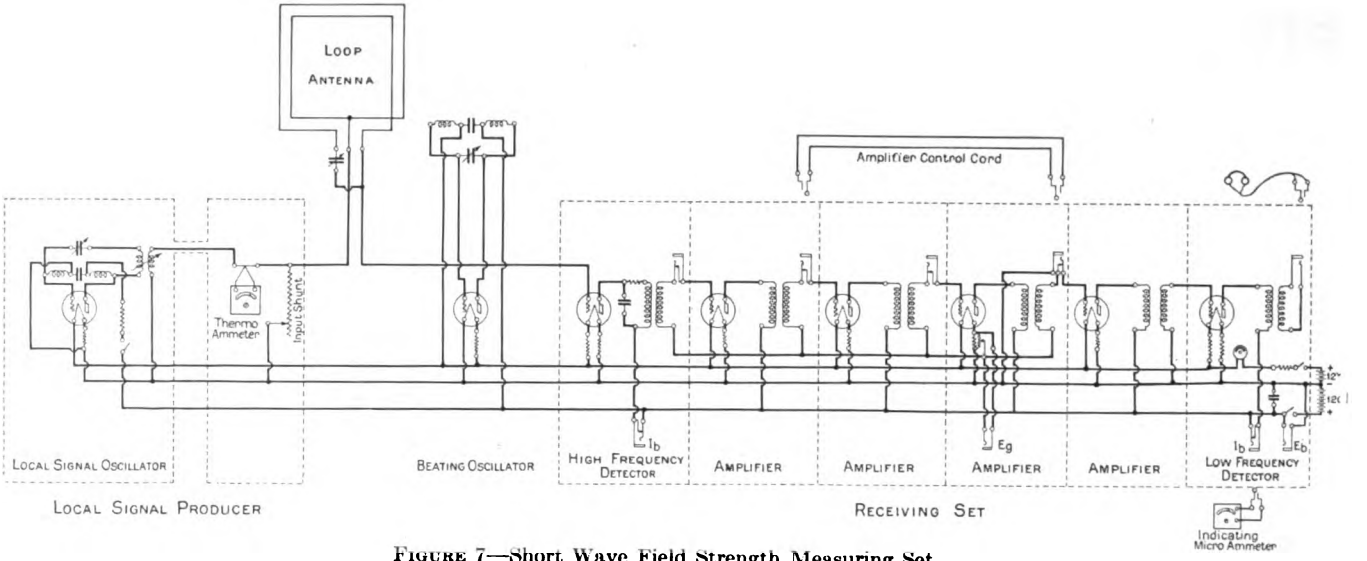

FIGURE 7—Short Wave Field Strength Measuring Set

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delivered to them at exactly the same frequency. At the same time, the original frequency of the local signal is well off the loop tune, and induction in to the loop is so reduced that only a moderate amount of shielding is required.

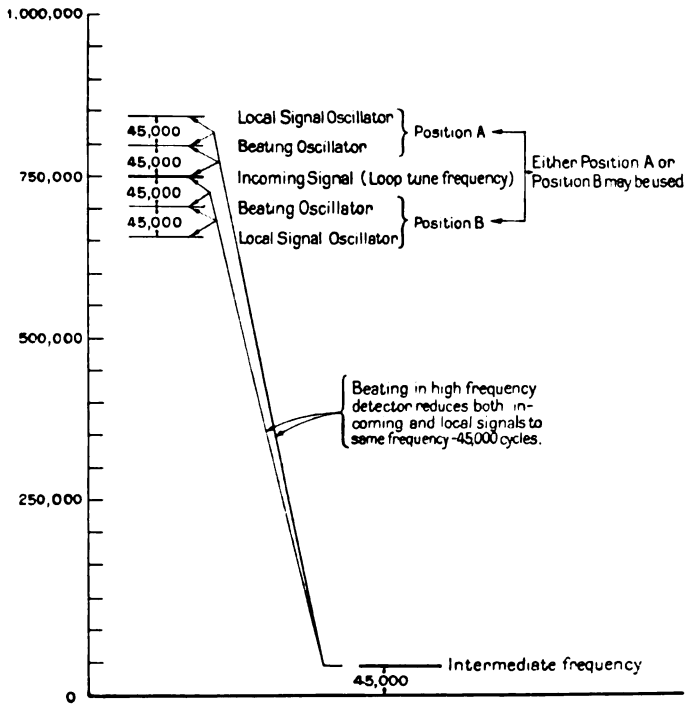

FIGURE 8—Frequency Diagram—Short Wave Field Strength Measuring Set

The resistance shunt thru which the local signal is introduced is placed in the ground lead of the loop. Thus the shunt is not in the loop circuit proper, but, viewed from the input terminals of the receiving set, is in series with the parallel resonance circuit formed by the loop and its tuning condenser. Since the local signal voltage impressed on the receiving set comes directly from the shunt and is not increased by resonance, the current thru the shunt is larger than in the case of the direct method used in the long wave sets, and no attenuation net work is needed. In effect the voltage across the shunt is compared by the receiving set with the voltage set up by the incoming signal across one half of the loop. The two voltage sources are in series in a very high impedance circuit. The low impedance shunt has, therefore, no appreciable effect on the interaction of the loop and the receiv-

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ing set. On the other hand, the loop, acting as a trap circuit, has sufficient impedance, even at the off-tune frequency of the local signal, to require that a simple experimental correction be made for it. The correction factor is determined as a part of the calibration of the set by taking the ratio of the voltage impressed on the receiving set from the shunt with the loop cut out of the circuit, to that impressed when the loop is in the circuit. Figure 9 gives curves of the correction factor α for a representative set for different frequencies of operation and for the two possible frequency relations between the incoming and local signals. The voltage applied to the receiving set by the

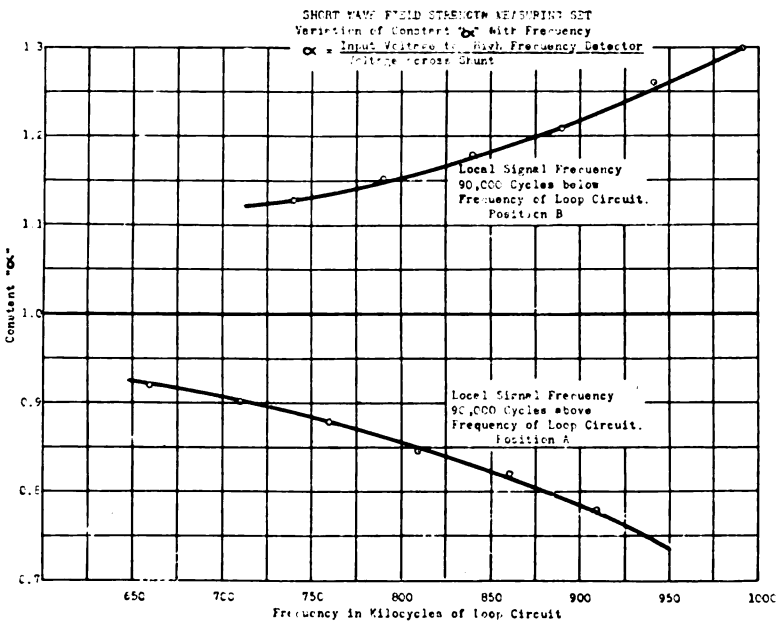

FIGURE 9

local signal input system is then: V (in millivolts) $= I_L \alpha R_s$, where I_L is the current in the shunt in milliamperes measured directly by a series thermocouple as indicated in the circuit diagrams, α is the correction factor, and R_s is the resistance of the shunt in ohms.

The potential applied to the receiving set as a result of the action of incoming waves of field intensity E micro-volts per meter is one-half that across the loop terminals or,

$$V = \frac{1}{2} \frac{4\pi^2 f^2 LAN E \times 10^{-15}}{3R} \text{ millivolts.}$$

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Transposing: $E = VK$ micro-volts per meter

where $K = \frac{0.152\,R}{f^2 L A N} \times 10^{15}$.

In the above.

f = frequency in cycles per second.
L = Inductance of loop in henrys.
A = Area of loop in square centimeters.
N = Number of turns in whole loop.
R = Total radio frequency loss resistance of loop circuit in ohms.

V is measured by comparison with the voltage across the shunt. E is derived from it thru the agency of the factor K, which is a calibration constant of the set. The short wave measuring set thus differs from the long wave set in that the inductance and resistance of the loop must be accurately known as well as its turns-area.

The distributed capacity of the loop and its connecting leads are determined by the well-known method of finding the values of the calibrated tuning condenser required to give resonance at various wave lengths, plotting these capacities against the corresponding wave length squared, and extrapolating the straight line thus obtained to its intercept on the capacity axis. Figure 10 shows the data thus plotted for a representative loop in which the distributed capacity was found to be 25 micro-micro-farads. Adding this to the capacity of the tuning condenser at resonance for some particular frequency, the inductance of the loop may be calculated by the usual method. In the loop mentioned the inductance is 156 micro-henrys.

After trying out several methods it was found that the resistance of the loop circuit could be best determined from the resonance curve by the capacity variation method. Each measuring set has permanently installed in parallel with the main tuning condenser a calibrated single plate variable condenser for the carrying out of this method. The radio frequency detector tube is one in which the change in plate current is proportional to the square of the radio frequency voltage impressed on its grid. In other words, it may be used as a vacuum tube voltmeter. The beating oscillator, with reduced coupling to the loop, serves as a source of constant radio frequency power. Thus the resonance curve of the system may be run at any desired frequency by means of the single plate tuning condenser and a micro-ammeter plugged into the plate circuit of the radio

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frequency detector tube. The conditions of calibration are thus those of operation and the resistance derived from the resonance curve by the usual methods includes all losses in the radio frequency circuit. The accuracy of the set is dependent on the accuracy with which R is determined, and R sometimes varies appreciably with climatic conditions. The method of

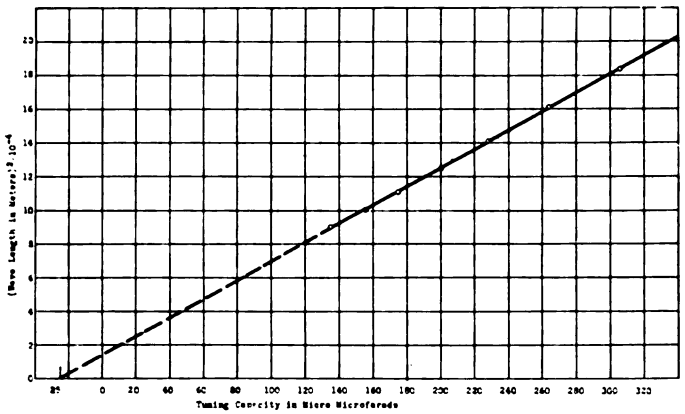

FIGURE 10—Short Wave Field Strength Measuring Set—Determination of Distributed Capacity of Loop

calibration is fortunate, therefore, in that no extra apparatus is needed, and it may be carried out in a few minutes wherever the set is in use. For the particular loop mentioned above, the variation of R with frequency is given in Figure 11. This loop has six turns and is a square 154 centimeters (59.7 inches) on a side. From these data, the factor K may be evaluated. It is given for the frequency range covered by the set in Figure 12.

In using this type of set, our practice is to dispense with ear comparisons and employ a micro-ammeter in the plate circuit of the audio frequency detector as the indicating means. The audio frequency detector then acts as a vacuum tube voltmeter to measure the amplitude of the carrier of the incoming radio telephone signals. Unless the transmitting station is badly over-modulating, the micro-ammeter is unaffected by the speech or music being sent. It is the carrier field strength which is measured, without reference to the degree or nature of the modulation.

The operation of the set is as follows: The desired signal is picked up by the loop and receiving set and brought to a volume which gives a satisfactory reading on the indicating instrument.

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By means of the fine adjustment condensers, and by watching the indicating instrument, the loop is tuned to exact resonance and the beating oscillator is set to place the intermediate frequency in exact resonance with the 45,000 cycle selective circuit of the amplifier. The loop is also oriented to give maximum response.

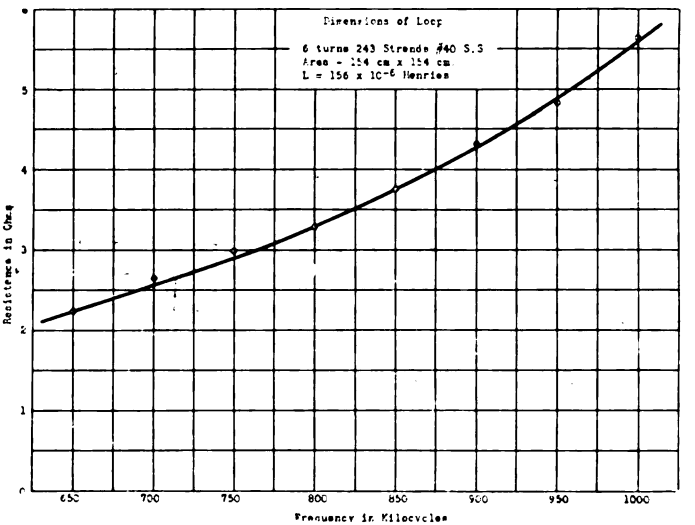
Dimensions of Loop
6 turns 243 Strands #40 S.S
Area = 154 cm x 154 cm
L = 156 x 10⁻⁶ Henries
Resistance in Ohms
Frequency in Kilocycles

FIGURE 11—Short Wave Field Strength Measuring Set—Variation of Loop Circuit Resistance with Frequency

The instrument reading is then recorded. Since the vacuum tube voltmeter indicates by virtue of the change in its plate current produced by the input voltage, a reading must also be

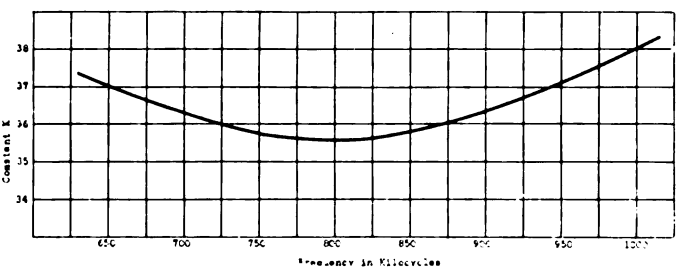

FIGURE 12—Short Wave Field Strength Measuring Set—Variation of Constant "K" with Frequency

$$K = \frac{\text{Voltage across half of loop (Millivolts)}}{\text{Field Strength } (\mu V/M)} = \frac{0.152\,R}{f^2 L A N} \cdot 10^{16}$$

Based on loop:
6 turns 243 strands No. 40SS.
154 cm. × 154 cm. (59.7 in. × 59.7 in.)
$L = 156 \times 10^{-6}$ henrys

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taken with the incoming signal cutoff. This is accomplished by shutting off the beating oscillator for a moment and recording the instrument reading, which is lower than with the signal on. The local signal oscillator is then started, set approximately to its proper frequency and the shunt adjusted to give a suitable value of input. A beat note is now heard between the 45,000 cycles due to the incoming signal and that due to the local signal. When this beat note is reduced to zero by means of the local signal oscillator frequency control, the local signal has been set exactly to its proper frequency position. If the transmitting station is co-operating it is then shut down, or if not co-operating, the loop is turned 90° to balance its signals out. Following this, the input shunt is adjusted to give a *difference reading* on the indicating instrument, due to the local signal, exactly the same as that which was given by the incoming signal. The measurement is now completed except for recording the various settings. The whole process takes 3 to 5 minutes, depending on the skill of the operator, and strength of signal, amount of interference, and so on.

A sample data sheet for use with this type of set is illustrated in Figure 13. Items 1 to 8 give general information relating to the test. Items 9, 11, and 16 are the condenser settings of the loop and oscillators. From Item 9 and a calibration curve, the frequency of the incoming signal (Item 10) is recorded in kilocycles. From Items 9, 11, and 16 one knows whether the signal is above or below the oscillators in frequency (Item 12) and the proper branch of the calibration curve is selected for the reading of the correction factor α. Items 13—14 and 17—18 are the "signal on" and "signal off" readings of the indicating micro-ammeter for the incoming and locally produced signals respectively. Their two differences (Items 15 and 19) should be equal.

Item 20 is the resistance of the local signal input shunt, Item 21 the series thermo-ammeter reading in scale divisions, and Item 22 the same in milliamperes. $I \times R$ (Item 20 times Item 22) gives the potential in millivolts impressed on the receiving set which, when multiplied by α the correction factor, is equal to the voltage impressed by the loop. The loop voltage times the factor K equals the field strength of the incoming signal in micro-volts per meter. Since α and K are thus ultimately multiplied together, it is a convenience to do this once for all and a combined factor $\beta = \alpha K$, is usually plotted up for use in reducing data. Such a curve is shown in Fig. 14. β is entered

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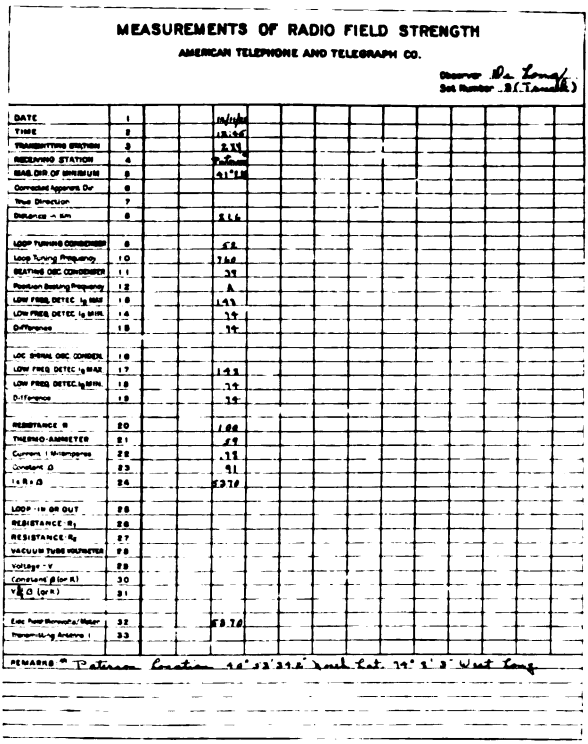
as Item 23. Item 24 $\times IR \times \beta$ is the field strength in microvolts per meter. Items 25 to 31 are for use with a slightly modified type of set. Item 32 is provided for collecting results at the bottom of the sheet. Item 33, the transmitting antenna, current is recorded when known.



MEASUREMENTS OF RADIO FIELD STRENGTH

AMERICAN TELEPHONE AND TELEGRAPH CO.

DATE	1			12/11/22													
TIME	2			12:06													
TRANSMITTING STATION	3			2XY													
RECEIVING STATION	4			Paterson													
MAG. DIR. OF MINIMUM	5			41°18													
Corrected Apparent Dir	6																
True Direction	7																
Distance - km	8			516													
LOOP TUNING CONDENSER	9			52													
Loop Tuning Frequency	10			760													
BEATING OSC CONDENSER	11			39													
Position Beating Frequency	12			A													
LOW FREQ. DETEC. Ig MAX	13			1.93													
LOW FREQ. DETEC. Ig MIN.	14			.79													
Difference	15			.79													
LOC. SIGNAL OSC. CONDEN.	16																
LOW FREQ. DETEC. Ig MAX	17			1.93													
LOW FREQ. DETEC. Ig MIN.	18			.79													
Difference	19			.79													
RESISTANCE R	20			1.00													
THERMO-AMMETER	21			.59													
Current I Microamps	22			.13													
Constant C	23			91													
I x R x C	24			5970													
LOOP - IN OR OUT	25																
RESISTANCE R_1	26																
RESISTANCE R_2	27																
VACUUM TUBE VOLTMETER	28																
Voltage - V	29																
Constant β (or K)	30																
V x C (or K)	31																
Exc. Feet Remarks/Meter	32			59.70													
Transmitting Antenna I	33																

REMARKS Paterson Location 40°32'24.6" North Lat. 74° 2' 3" West Long.

FIGURE 13—Data Sheet used for Recording and Reducing Data

Each measurement requires one column on the data sheet. The sample column shown is data taken on December 11, 1922 at a point near Paterson, New Jersey, while measuring transmission from Station 2XY. The auto truck measuring set described in subsequent paragraphs was used.

The photograph Figure 15 illustrates the original laboratory set up of the first short wave measuring set. It was with this apparatus that the first measurements of the field strength received from the S. S. *America* were made in February and March, 1922. One of the best sets of data obtained is reproduced in Figure 16 as illustrative of the utility of such measure-

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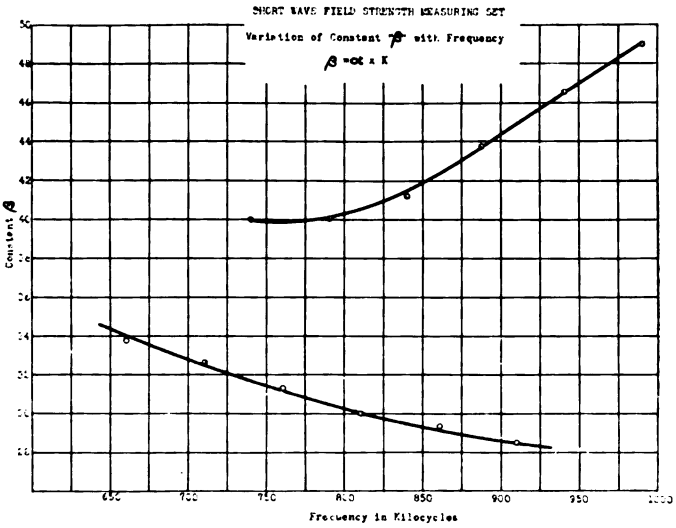
SHORT WAVE FIELD STRENGTH MEASURING SET
Variation of Constant β with Frequency
β = σt x K
Constant β
Frequency in Kilocycles

FIGURE 14

ments in studying the law of short wave transmission over water and of giving a quantitative insight into the phenomena of night and day transmission, fading and the like.

Following the success of this original measuring set, models were made up for more general field use. These were more compact, rugged, and transportable in physical form, but electrically were so similar to the original set that the circuit diagram of Figure 7 represents their circuits almost exactly. One of them is shown set up in a small shack in Figure 17. The two boxes mounted on the loop contain the beating oscillator and the loop tuning condensers. On the bench the large box in the foreground contains "B" batteries and filament controls. The long box in the rear is the receiving set. The two boxes at the front edge are the local signal oscillator and input shunt with its thermocouple milliammeter. Between them is the output indicating instrument. A twelve-volt storage battery completes the outfit. Cords and plugs are provided for all connections between boxes. The loop folds up into a special packing case for shipment. The boxes may be shipped in a padded trunk. The battery rack under the bench is used with the permanent set up illustrated, the "B" batteries in the set being too small for long continued service. It will be noted from Figure 17 that all wiring and metal net works (except for a short piece of insulated stove pipe) have been eliminated from the neighborhood of the set.

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One of these sets with a different form of loop antenna has been installed in a small motor truck for mobile field use. It is illustrated in Figure 18. An interior view looking from the rear

FIGURE 15—Original Short Wave Field Strength Measuring Set

is given in Figure 19. The truck set has for the past few months been engaged in an investigation of transmitting conditions for radio broadcasting in and around New York City. One of the interesting things shown by the investigation is that the transmitting efficiency of a broadcasting antenna erected on the roof of a steel building may be very much affected by the height of that building. For instance, with station 2XY, located on the

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top of the 24-story telephone building at 24 Walker Street, New York, it was found that the field strength received at a fixed measuring point varied with the wave length in the manner indicated in Figure 20. The general nature of this characteristic could have been determined qualitatively by means of ordinary listening tests, but a satisfactory study of the phenomena was possible only with the aid of absolute and quantitative measurements of radiated field. This study has been very useful in

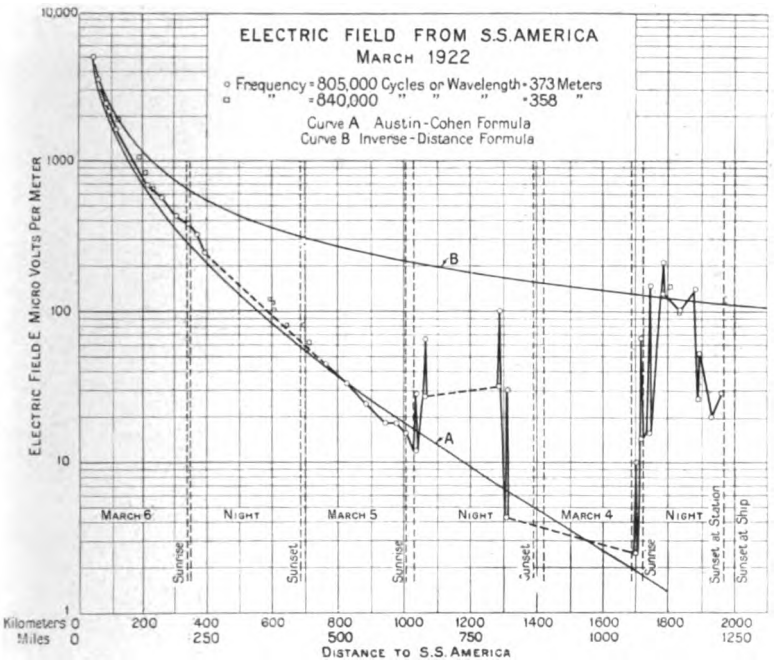

FIGURE 16

enabling us to predict with a fair degree of certainty the results to be expected from any particular building, as was the case with the proposal to locate a city broadcasting station on the Municipal Building. Later the tests were extended to mapping the transmission distribution of stations in lower Manhattan. Three stations were mapped: 2XB (WEAF), 2XY (WBAY), and 2XW (Municipal Building experimental antenna). The results of the series of tests are plotted in Figure 21. It will be seen that at 400 meters these stations are handicapped in transmitting northward thru the maze of steel structures of the island. Also it is apparent that the two high buildings are less favorable sites than the 14-story building at 2XB.

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The results so far obtained demonstrate that field strength measuring sets are valuable experimental tools. For this reason it has seemed worth while to us to develop the short wave set into a form as compact and portable as possible. Figure 22 shows such a set. This outfit is self contained within the parts shown in the picture. It is intended to be enclosed entirely in two bags or suit cases of the kind used by salesmen for carrying samples. Thus it can be easily transported in an automobile or even carried by hand for reasonable distances. The loop

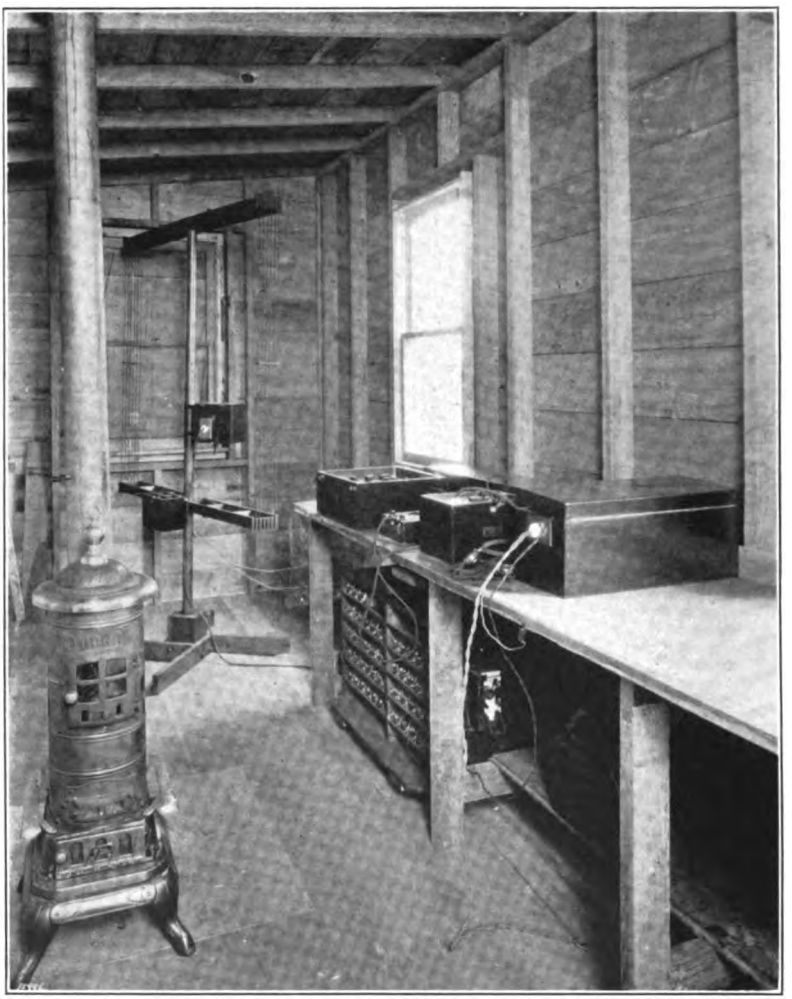

FIGURE 17—Short Wave Field Strength Measuring Set as Installed in the Measurement Shack at Cliffwood, New Jersey

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collapses compactly. The upper box contains the receiving set complete including "A" and "B" batteries, which are dry cells. The lower box contains the local signal input apparatus

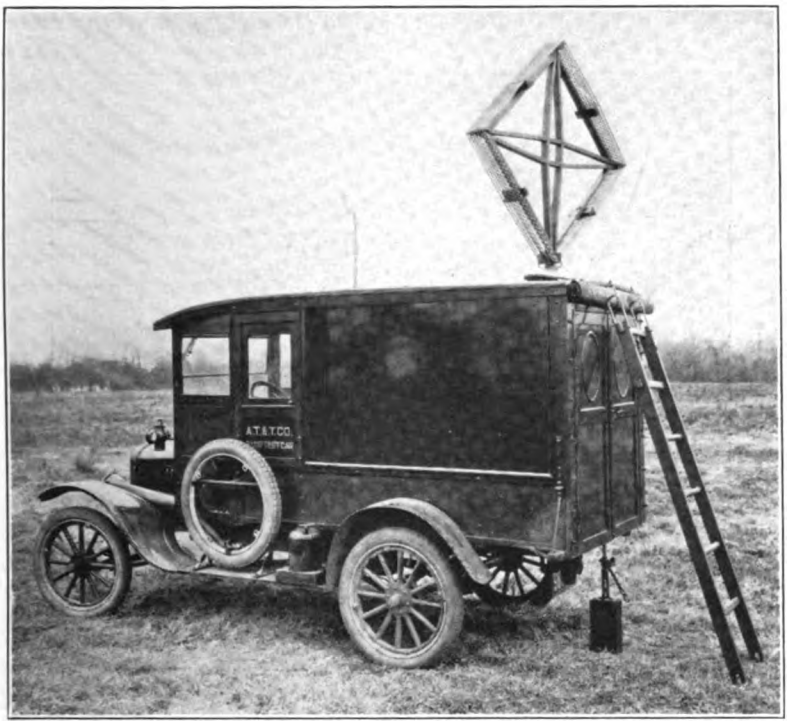

FIGURE 18—Truck Installation of Short Wave Field Strength Measuring Set

together with all its batteries. The alternating current voltmeter shown alongside enables the vacuum tube voltmeter in the set to be calibrated anywhere that an alternating current lighting circuit is available. This is not essential since several spare calibrated tubes may be carried inside the set. Back panel views of the receiving set and local signal producer are shown respectively in Figures 23 and 24. A circuit diagram is given in Figure 25. In order to simplify the diagram, several jacks, amplification control, and battery switches have been omitted from it. Western Electric type N tubes (popularly known as "peanut tubes") are used thruout, which accounts for the compactness of the batteries. The arrangement differs from the earlier sets essentially only in the local signal input unit. The oscillator feeds into the shunt thru an amplifier to give stability. The current in the shunt is measured by means

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of a vacuum tube voltmeter rather than a thermo-ammeter. There is also a minor difference in that the beating oscillator feeds into a small pick-up coil rather than into the loop directly. This outfit has not as yet been given a sufficiently thoro tryout to enable us to say with assurance that it is successful. It is with-

FIGURE 19 Interior View of Truck Installation

out doubt, however, capable of success, and we may look forward confidently to the time when the field strength measuring set will be almost as convenient and usable as the wavemeter is today.

Very little has been said above about the range and sensitiveness of our short wave measuring sets. It has not been found desirable to cover a wave length range much wider than two to one in a particular set. The short wave sets have been designed

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for a nominal range of 300 to 600 meters (1,000,000 to 500,000 cycles). Some of them have been used as high as 1,000 meters by adding loading condensers. This makes the calibration less determinate, and it is preferable to provide new loops and oscillator coils where radical shifts in range are desired. The later sets have been made with interchangeable socket mounted coils for this reason.

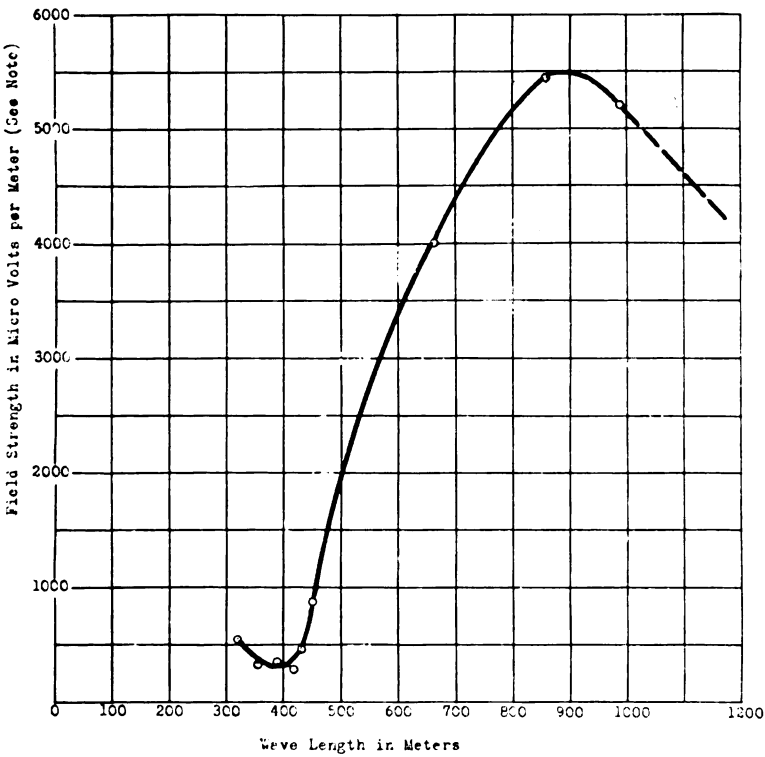

FIGURE 20—Variation of Field Strength with Wave Length. Measurements taken on 2XY (24 Walker St., New York City) at Cliffwood, New Jersey. NOTE: Field Strengths Corrected to 5 amps. Antenna Current at all Wave Lengths. Normal Antenna Current at 400 Meters is 10 amps.

By using the radio frequency detector directly as a vacuum tube voltmeter and dispensing with the rest of the receiving set, field strengths as high as 100,000 micro-volts per meter or more may be measured. The range is continuous from such values down to a minimum of about 10 micro-volts per meter, at which point the accuracy becomes questionable. Even lower field strengths may be measured approximately, however. Two

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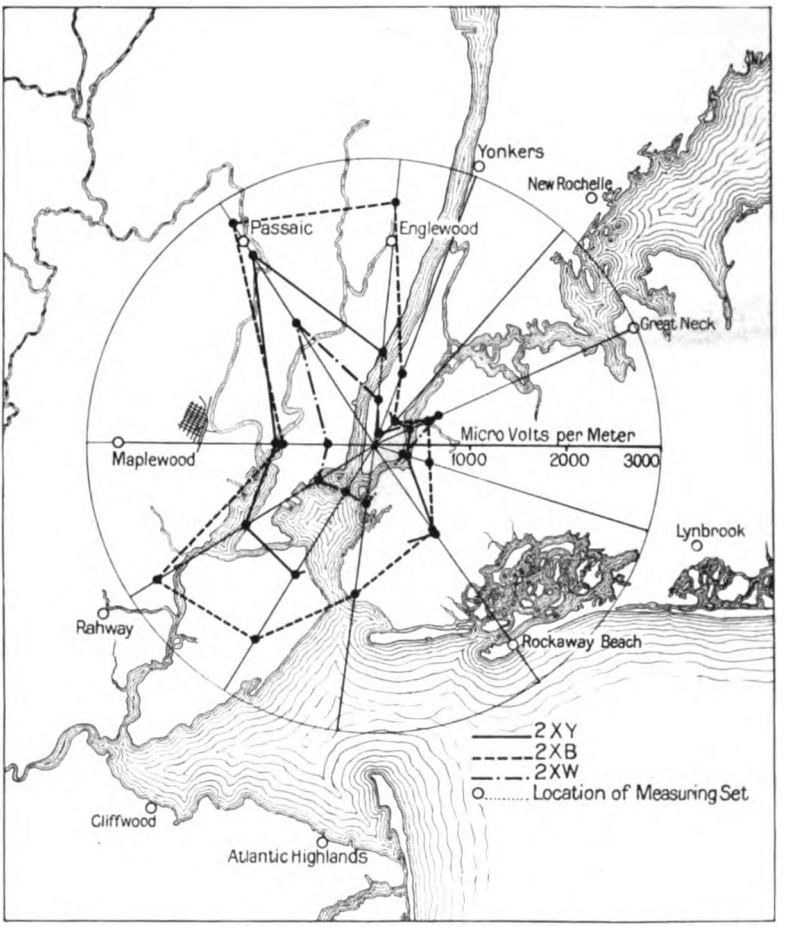

FIGURE 21—Polar Diagram of Field Strength Produced by Stations 2XB, 2XW, and 2XY. Corrected to 100 Watts in Antenna and a distance of 25 km. (16 miles)

or three hundred micro-volts per meter is about as low a radio telephone signal strength as can be received on the average high class radio receiver with any satisfaction under present day conditions of interference, so that the sensitiveness of the measuring sets seems adequate for any ordinary purpose. As was mentioned in a previous paragraph, only the carrier component of the transmission is measured, and ordinary modulation has no effect on the indicating instrument. Also static, which gives serious interference to reception of the speech or music, leaves the instrument practically unaffected. Even during summer, static

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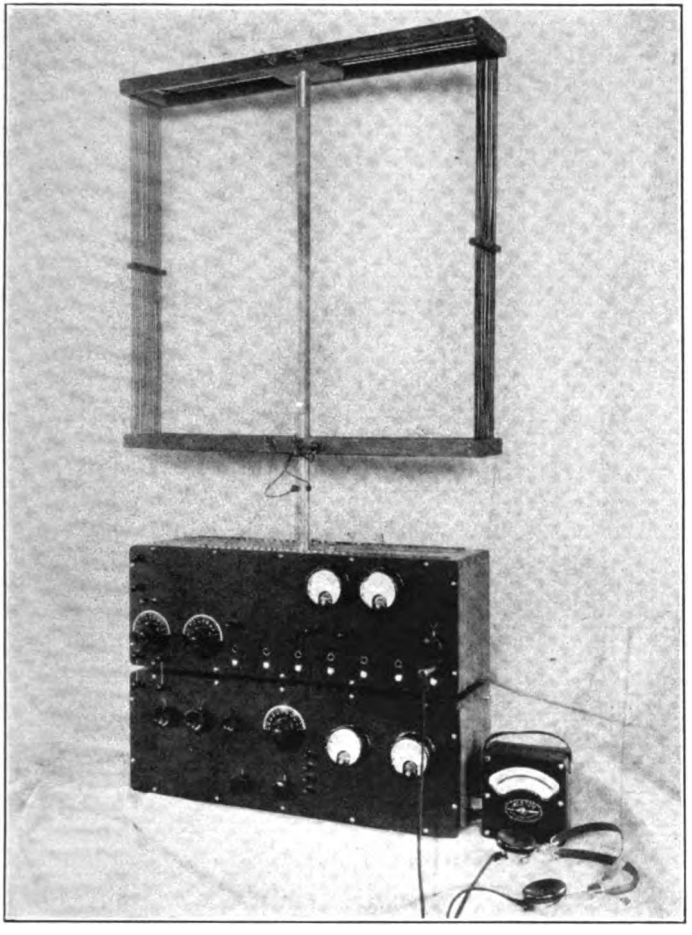

FIGURE 22—Portable Short Wave Field Strength Measuring Set

measurements can be made down to about 100 micro-volts per meter when a thousand micro-volts per meter or more would be required for satisfactory reception. The principal reason for this is that the direct current indicating instrument does not respond to alternating speech or noise currents in the output of the audio frequency detector. Interference from other radio telephone stations transmitting carriers of their own is obviously a different matter and may be very troublesome.

For comparing various incoming signals at or near the same frequency, the precision of the sets might almost be said to be limited only by the skill of the operator and the stability of the signals. When the results are expressed in absolute terms

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of a vacuum tube voltmeter rather than a thermo-ammeter. There is also a minor difference in that the beating oscillator feeds into a small pick-up coil rather than into the loop directly. This outfit has not as yet been given a sufficiently thoro tryout to enable us to say with assurance that it is successful. It is with-

FIGURE 19—Interior View of Truck Installation

out doubt, however, capable of success, and we may look forward confidently to the time when the field strength measuring set will be almost as convenient and usable as the wavemeter is today.

Very little has been said above about the range and sensitiveness of our short wave measuring sets. It has not been found desirable to cover a wave length range much wider than two to one in a particular set. The short wave sets have been designed

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for a nominal range of 300 to 600 meters (1,000,000 to 500,000 cycles). Some of them have been used as high as 1,000 meters by adding loading condensers. This makes the calibration less determinate, and it is preferable to provide new loops and oscillator coils where radical shifts in range are desired. The later sets have been made with interchangeable socket mounted coils for this reason.

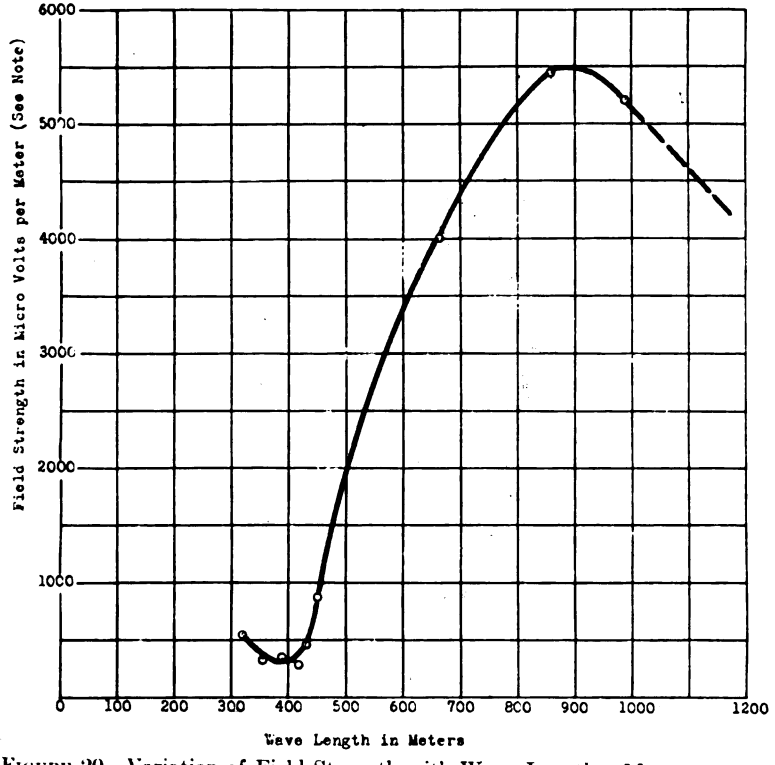

FIGURE 20—Variation of Field Strength with Wave Length. Measurements taken on 2XY (24 Walker St., New York City) a t Cliffwood, New Jersey. NOTE: Field Strengths Corrected to 5 amps. Antenna Current at all Wave Lengths. Normal Antenna Current at 400 Meters is 10 amps.

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micro volts per meter) we do not believe that they are to be trusted closer than ± 5 percent under the best operating conditions. Better calibration of sets may be expected to improve this, but it is quite sufficient for ordinary purposes. Where the signals are unstable in frequency or amplitude, interference is bad, or the operator unskilled, the results will be correspondingly less reliable.

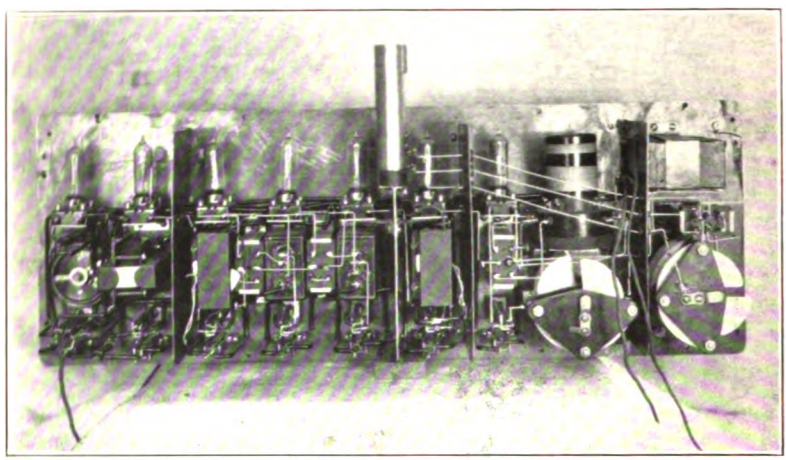

FIGURE 23 Interior View of Receiving Set Portion of Portable Short Wave Field Strength Measuring Set

MEASUREMENT OF RADIO NOISE

The problem of measuring radio noise is a considerably more puzzling matter than that of measuring the field strength of signals. First of all, the amount of noise received is dependent upon the directional and selectivity characteristics of the receiving system. In the present paper we will not enter into a consideration of these two factors, but will treat only the measurement of noise as received on apparatus we have used in experimental work. It should be noted, however, that the method of measuring noise described below may be used for comparing and evaluating the noise-reducing merits of receiving systems having various directional and selectivity attributes.

We have naturally approached noise from the telephone standpoint, since our primary interest is in radio telephony. Radio noise results in audio noise which comes to the ear of the listener and interferes with the understanding of sppech on the circuit. Within upper and lower limits set by the capabilities of the ear, the absolute volumes of speech and noise are not

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important as long as their relative volumes, that is, the ratio between their volumes, remains constant. This is a matter of common experience—changing the amplification of a receiving set to raise or lower the volume of received speech does not materially affect the interfering effect of static, because it is also raised or lowered in the same amount. It follows, therefore, that a good way of measuring noise should be to express it in terms of a volume of speech upon which it produces a certain

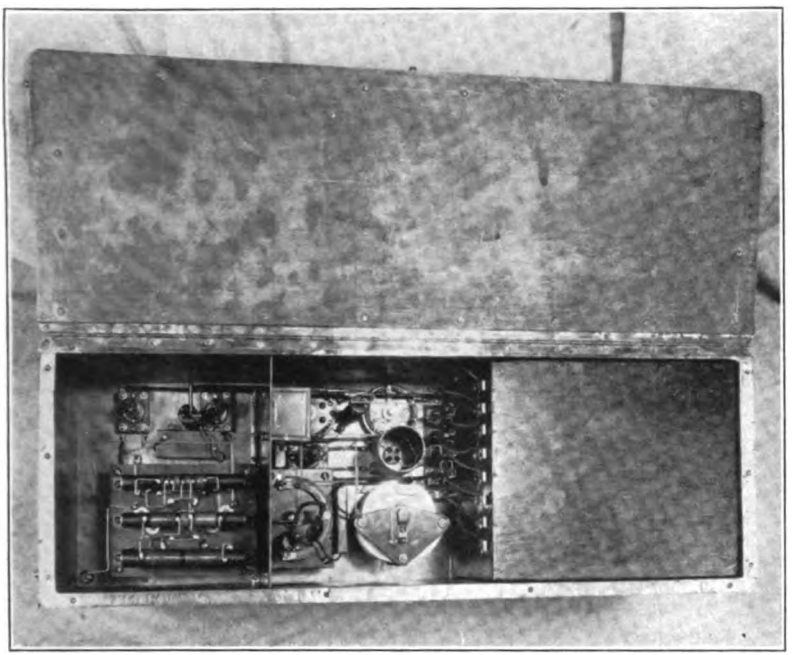

FIGURE 24—Interior View of Local Signal Producer Portion of Portable Short Wave Field Strength Measuring Set

standard interfering effect. Now, speech is a difficult thing to standardize, so that it is preferable to use some constant artificial source of sound which approximates speech in its effect on the ear and its reaction to the interfering effects of noise. For practical purposes it is found that an audio frequency tone, which flutters or varies back and forth uniformly in pitch between 600 and 1,400 cycles at a rate of about ten times per second, is a satisfactory form of artificial speech for the purpose. For the standard degree of interference produced on the artificial speech by noise, there are obvious reasons for selecting some sort of "end point." Such a suitable point is the one at which the

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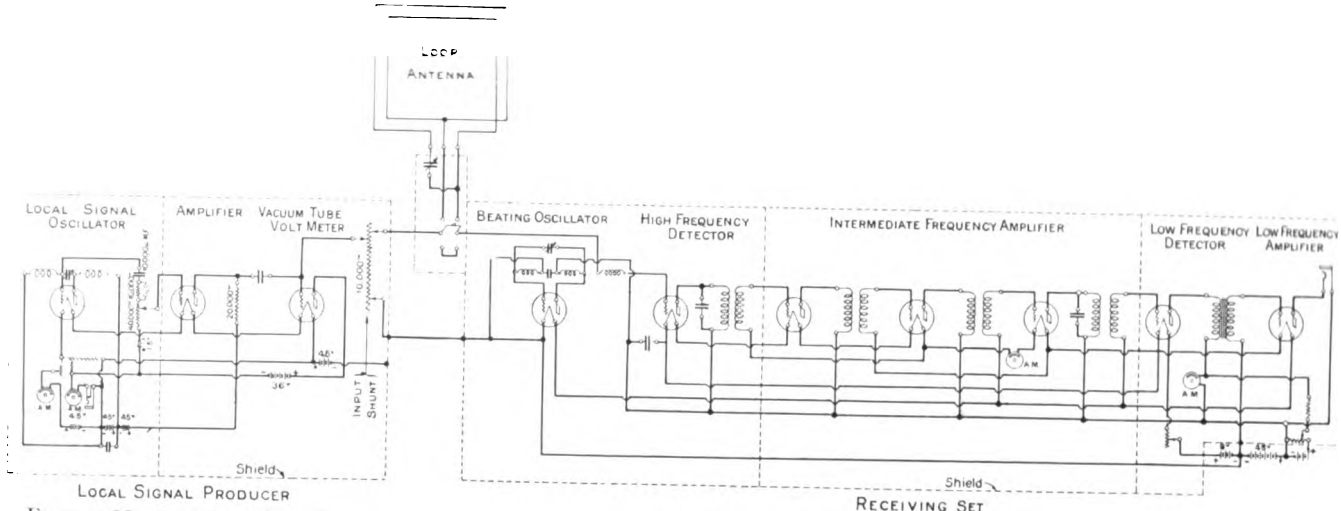

FIGURE 25—Portable Short Wave Field Strength Measuring Set. Circuit Diagram Simplified in Regard to Jacks, Amplification Controls, and Switches

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presence of the artificial speech is just discernable thru the noise. The method, then, involves the introduction into the noisy circuit being measured of a controllable measured volume of the artificial speech and the setting of this volume to the point at which the ear is just able to recognize its presence. This point can be located by different observers who have but little skill in the use of the method, with a variation among observers of less than about 50 percent. To the ear 50 percent is a small change. The radio noise itself goes thru variations within a season and occasionally within a few days which are several hundred times as large, so that the precision of measurement is quite sufficient for the purpose.

If measurements of this kind are to be comparable and of permanent value, the volume of the artificial speech must be expressed in suitable absolute terms. Since it is radio noise with which we are concerned, the artificial speech should be expressed in the fundamental unit of radio transmission, which is electric field strength and of which the accepted practical base is one micro-volt per meter.

If the artificial speech is introduced into the antenna of a field strength measuring set as a radio signal in the same way that the local signal is introduced for field strength measurement purposes, the receiving set becomes merely an electrical extension of the ear and the evaluation of incoming noise in terms of the amount of local artificial radio telephone speech which it all but extinguishes, is made directly at the radio frequency. The conditions are those which would obtain if the artificial speech signal were in fact received from a distant station the power of which is under control by the measuring operator and the field strength of which at the measuring station is known for various power settings. To apply this method to a short wave measuring set, the local signal-producing oscillator must be modulated a fixed standard amount (say 100 percent) by the artificial speech flutter tone. We have not as yet been concerned with noise measurements at short waves, but have carried out our work in the long wave lengths.

Since in our long wave telephone work we are chiefly interested in the type of transmission which suppresses the carrier and one side band in the early stages of the transmitting amplifier and transmits but a single side band, our noise measurements have been carried out in such a way as to make the results most directly applicable to this kind of system.

The artificial speech is introduced into the calibrated re-

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ceiving antenna in the form of a single radio frequency side band, and thus simulates incoming speech signals. Take, for instance, the case of artificial speech modulated onto a 56,000 cycle carrier. The upper side band when isolated by itself is a single continuous wave which varies in frequency from 56,600 to 57,400 cycles at a rate of about ten times per second. In practice this is a simple thing to produce. It merely requires a 57,000 cycle signal producing oscillator having a small motor-driven rotating condenser in parallel with its main tuning condenser, so as to cause the oscillator frequency to vary about 400 cycles each way from a mean of 57,000 cycles during each revolution of the rotating condenser, the rate of rotation being about ten times per second. A field strength measuring set may thus be readily adapted to measuring noise.

During the development and study of this method of measuring noise, data were taken at Cliffwood, New Jersey, nearly every hour during working days over a period of several months. An ordinary open antenna was used, the constants of which have been measured only approximately, so that the data are only approximately correct when referred to their absolute scale. For this reason we have not considered it desirable to give any of them in this paper.

The most interesting samples of data we have in the way of noise measurements are those being made in London contemporaneously with the measurement of field strengths received from Rocky Point.

In Figure 26 are plotted the noise measurements at London for the same 52-hour test period as the field strength values given in Figure 6. For making the noise measurements the field strength measuring set was modified along the lines discussed above and as indicated in Figure 4. The abscissas of the curves are hours of the day and the ordinates are the minimum values of single side band artificial speech in micro-volts per meter which could be heard thru the noise.

Since the noise measurement gives the minimum field strength audible thru the noise, satisfactory speech transmission of course requires a field strength many times larger. The factor of increase needed depends upon the quality of speech received, that is, upon the ease with which the speech could be followed if no noise at all were present. The nature of this factor of increase is brought out by the plot or diagram in Figure 27. The abscissas are ratios of received field strength and measured noise for the Rocky Point-London tests of February 11, 12, and

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13, 1923, the field strength and noise values of which have been given in Figures 6 and 26. The ordinates are the corresponding percentage of words estimated as satisfactorily received in London during the part of each hourly test period in which speech was transmitted. The speech consisted simply of geographical names such as cities, states, rivers, and the like spoken slowly and distinctly, but quite disconnected and without context.

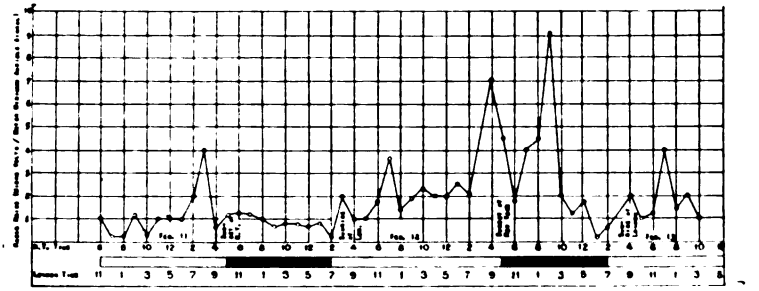

FIGURE 26—Noise Measurements taken in London, England, February 11, 12, 13, 1923. Frequency 57,000 Cycles

It will be seen that a field strength-noise ratio of about 30 marks a fairly definite division line. Above this value, good reception of the speech predominates, while below it the reception rapidly declines. The data shown are too meagre to warrant the drawing of a curve, but the general form which the curve would take may be visualized from the scatter of points shown. A considerable portion of the scattering in this set of data, which was selected at random, is due to the fact that the field strength and noise measurements were not simultaneous, but separated by ten or fifteen minutes. They are shown as simultaneous in Figures 6 and 26 because they are there referred to the beginning time of the hourly test periods, each of which had a duration of about 25 minutes.

It should not be inferred that the value 30 for the factor of increase has any general significance. It represents, for the speech quality being transmitted from Rocky Point during the tests, what might be termed the lower limit of speech reception. For such a grade of transmission as is given on good wire lines the ratio is several times this value. The principle illustrated is, however, of fundamental importance—noise measurements taken by this method, when multiplied by a suitable factor, give directly the field strength which is required to produce a grade

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of reception corresponding to the factor chosen. There is every reason to believe that the principle applies as well to telegraph reception as to telephone, provided a properly evaluated factor of increase is chosen. The two cases are parallel, since the process of receiving single side band speech transmission is the same as that of receiving continuous wave telegraph signals by the heterodyne method.

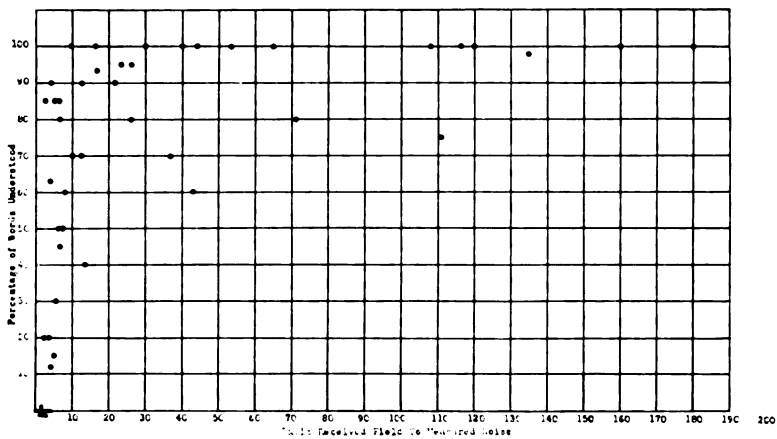

FIGURE 27—Relation Between Speech Reception and Signal to Noise Ratio. Transatlantic Radio Telephone Tests, February 11, 12, 13, 1923

In taking and interpreting the noise data several things have to be respected. To begin with, the receiving set itself must be free of appreciable noise. This can be tested by replacing the antenna with an equivalent impedance such as a dummy antenna having no noise pick-up. The room noises must be small enough so as not to be appreciable to the operator in comparison with the radio noise in the head receivers. The radio noise in the receivers should be adjusted by means of the receiving set amplification, to a comfortable volume which is kept about the same from test to test irrespective of whether the radio noise, in absolute terms, goes thru wide variations. This allows the ear to work under substantially constant conditions. At this point it might be well to distinguish clearly between the practice and philosophy of this method of measuring noise and that of the method of measuring "signal audibility" by the shunted telephone receiver, which has now outlived its usefulness. In the latter method no noise measurement is involved. The signal and radio noise are reduced together to the point where they

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are lost in the room noise or, if the room be quiet, to the limit of sensitiveness of the operator's ears. In the former method, noise only is measured (tho in terms of signal). The noise is kept substantially constant at a comfortable volume thruout the measurement, so that the ear is under a normal condition. The artificial speech is independently reduced until the noise all but blots it out. Room noise and the absolute sensitiveness of the operators' ears are not direct factors. The physiological and psychological aspects of the two schemes are indeed as different as are their purposes.

For the benefit of those who may wish to try this method of measuring radio noise we would, in the interest of uniformity in interpretation of results, suggest the following specifications for the artificial speech used. As listened to in the telephone receiver, the tone should traverse back and forth from 600 cycles to 1,400 cycles at a rate of ten complete round trips per second. At the radio frequency input the amplitude should be substantially constant over the band of frequencies traversed. The frequency variation should not be a sine function of time but more nearly linear, the resulting audio frequency increasing uniformly from 600 cycles to 1,400 cycles, abruptly reversing and going uniformly back to 600 cycles where it abruptly starts up again. This, combined with the constant amplitude, spreads the energy evenly over the frequency range covered. A small semi-circular-plate rotating condenser, in parallel with the tuning condenser of the local signal-producing oscillator, can be adjusted to meet these requirements properly.

Taking readings when the radio noise is the steady drum-fire type of static is relatively easy. When it is a steady background with occasional heavy crashes, the crashes must, perforce, be neglected and the background measured. When the crashes are loud and frequent enough to be of real importance, they have the effect of partially deadening the ear so that they produce somewhat the same effect on the hearing of the artificial speech in between times as they would have on the understanding of speech. Making the setting is more difficult, however, and the method is no doubt least accurate in measuring this type of noise.

SUMMARY: The paper divides naturally into three sections. The first section briefly analyses the radio transmission circuit into (a) the sending or radiating portion, (b) the transmitting portion consisting of the ether path thru which the radiated waves travel, and (c) the receiving portion. The relation of these from the standpoint of the radio transmission engineer is discussed, pointing out the need of quantitative data as to electric field

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strengths of waves and of radio noise conditions to allow of rational design of radio systems. The second section is devoted to descriptions of apparatus which has been developed for measuring electric field strengths of radio waves, its theory and method of use. Illustrative data are given showing useful practical results already obtained at both short and long wave lengths. The third section deals with the measurement of radio noise. A useful method is described and is illustrated by examples of data from recent transatlantic telephone tests.

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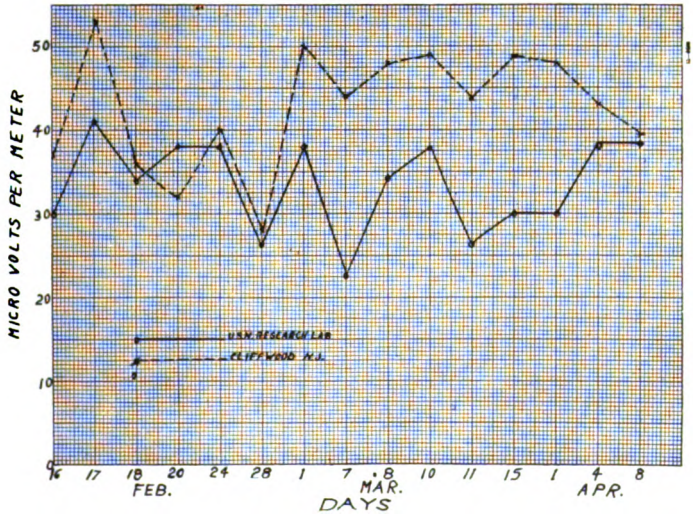
Discussion on

"NOTE ON THE MEASUREMENT OF RADIO SIGNALS"*

By

C. R. Englund

L. W. Austin (by letter†): The observations taken by Mr. Englund on Nauen have given an opportunity for comparing his radio frequency comparison method of measuring signals with the method used at the United States Naval Radio Research Laboratory, in which a telephone comparator is employed. In this



comparator, the telephones are thrown from the receiving circuit into a circuit supplied with known audio frequency current supplied by a General Radio tuning fork generator and potentiometer which is adjusted to give the same loudness of sound in the telephones as the signal.

The Table and curves give the observations taken on the corresponding days by the two methods. The average of Mr.

* Proceedings of The Institute of Radio Engineers, February, 1923, volume 2, number 1, page 26.

† Received by the Editor, February 10, 1923

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Englund's observations is about twenty-four percent. higher than the Washington observations. About half of this difference is to be explained by the difference in distance of the transmitting station from the two receiving points, which brings the agreement within the probable accuracy of the methods.

The two curves are remarkably alike in form except for the observations on February 20, and those on April 4 and 8. On the last two dates the Cliffwood observations were taken about two hours later than those in Washington.

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SOME IMPROVEMENTS IN THE POULSEN ARC*†

PART II

BY

P. O. PEDERSEN

(PROFESSOR IN THE ROYAL TECHNICAL COLLEGE, COPENHAGEN, DENMARK)

THE EFFICIENCY OF THE ARC

The efficiency of the arc depends upon the shape of the arc voltage curve. For the sake of simplicity, we shall only consider those cases where the choke coils are of such a value that the supply current, I_o, may be considered constant. The total energy supplied to the arc and the oscillating circuit during each period is then determined by

$$W_o = \int_t^{t+\tau} I_o e_1 \, d\,t, \tag{1}$$

where e_1 is the arc-voltage and τ the period.

We will further confine our consideration to the case in which the arc-voltage is equal to E_b for any value of the arc current greater than I°, where I° is very small compared with I_0 (see Figure 1 A and B). Most of the supply current will—under these circumstances—whether the arc voltage has one or two peaks—pass thru the arc while the arc voltage has the value E_b; the energy consumed in the arc is, therefore, approximately given by

$$W_a = I_o E_b \tau \tag{2}$$

The amount of energy, P, delivered to the oscillating circuit in each period is consequently determined by

$$P = W_o - W_a = \int_t^{t+\tau} I_o(e_1 - E_b) d\,t = I_o U, \tag{3}$$

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*Received by the Editor, November 28, 1922.

†(a) "On the Poulsen Arc and Its Theory," PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS, volume 5, pages 255-316, 1917.

(b) "Supplementary Note," volume 7, pages 293-297, 1919.

(c) "Some Improvements in the Poulsen Arc, Part I," volume 9, pages 434-441, 1921.

These papers are referred to above as (a), (b), and (c). For list of symbols see reference (a), pages 315, 316. (In the list of symbols and in the first part of paper (a), E_b is by mistake called E_c.)

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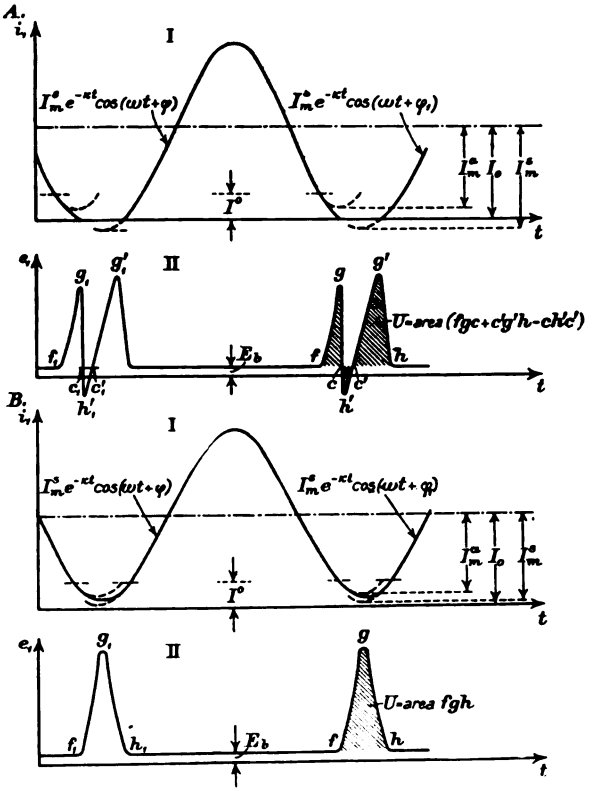

FIGURE 1—Arc Current i_1 and Arc Voltages e_1. A for double-peak operation. B for single-peak operation

where U is the area of the voltage peaks shown in Figure 1 A or B.

The efficiency, η, is therefore, determined by

$$\eta = \frac{P}{W_o} = \frac{U}{E_b \tau + U} = \frac{1}{1 + \frac{E_b \tau}{U}} \tag{4}$$

The efficiency will, for large arcs, often be about 50 per cent. L. F. Fuller[1] states that 50 per cent. is a theoretical limit for the efficiency, which limit normally is reached, but which cannot be passed. This is a mistake. There is no such theoretical limit. It will not violate any physical principle to have arc generators with 90 per cent efficiency, for instance. As shown above in equation (4) the efficiency for a given period depends solely on

[1] L. F. Fuller, PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS, volume 7, page 461, 1919.

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the ratio of the voltage E_b of the arc when burning to the peak area U, and there is absolutely no theoretical lower limit to this ratio.

As the idea about the 50 per cent limit is rather generally entertained it may be worth while to calculate the efficiency in some simple cases.

For the sake of simplicity we take the form of arc voltage curve (e_1) shown in Figure 2, where the peaks are of a rectangular

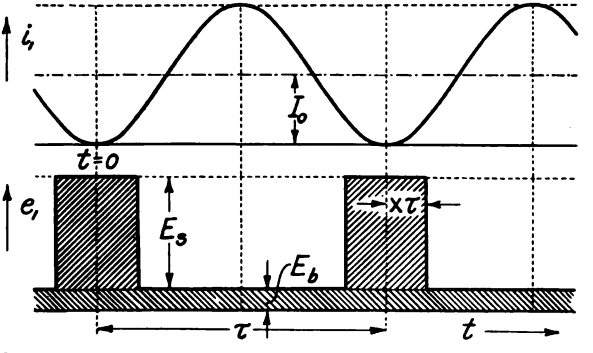

FIGURE 2—Diagrammatic Representation of Arc Current i_1 and Arc Voltage e_1

shape and where the arc current (i_1) is taken as a pure sine curve

$$i_1 = I_o\left(1 - cos\, 2\pi\frac{t}{\tau}\right)$$

With the symbols used in the figure we have—(comparing equations (1)—(4)):

$$W_o = \int_o^\tau I_o e_1\, dt = \tau I_o\,(2x E_s + E_b), \qquad (1')$$

$$W_a = \int_o^\tau i_1 \cdot e_1\, dt = \tau I_o\left[\left(2x - \frac{1}{\pi} sin\, 2\pi x\right) E_s + E_b\right] \qquad (2')$$

and

$$P = W_o - W_a = \tau I_o \frac{sin\, 2\pi x}{\pi} E_s \qquad (3')$$

Accordingly, the efficiency is determined by

$$\eta = \frac{P}{W_o} = \frac{sin\, 2\pi x \cdot E_s}{\pi\,(2x E_s + E_b)} = \frac{sin\, 2\pi x}{2\pi x + \pi\beta}, \qquad (4')$$

where

$$\beta = \frac{E_b}{E_s}.$$

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This efficiency is a maximum for the value of x_o determined by

$$tan\, 2\pi x_o = 2\pi x_o + \pi\beta, \tag{5}$$

and the corresponding value of η is

$$\eta_{max} = \frac{1}{\sqrt{1 + (2\pi x_o + \pi\beta)^2}} \tag{5'}$$

Corresponding values of η_{max} and x_o are shown in Figure 3 as functions of β. It appears from this figure, that $\eta_{max} = 1$ for $\beta = 0$ and is above 50 per cent for values of β smaller than 0.2.

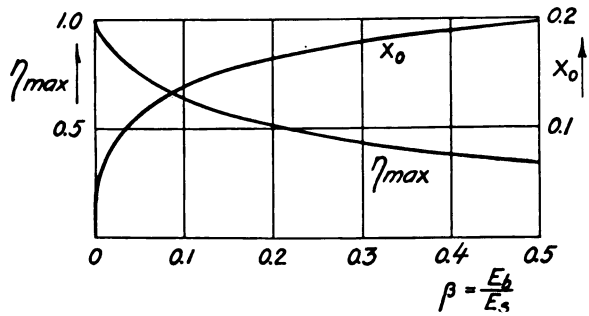

FIGURE 3—Diagrammatic Representation of Maximum Efficiency as depending upon the Ratio of the "Burning Voltage" E_b to the "Ignition Voltage" E_s

NON-HOMOGENEOUS MAGNETIC FIELD

In consequence of the preceding considerations, as shown in Figures 1 and 3, the best efficiency of the arc is obtained when the voltage E_b across the arc in the central portion of the period is kept as low as possible while the area of the peaks themselves should be as large as possible. This conclusion, combined with the knowledge of the working manner of the arc obtained thru the investigations described in the papers referred to above, may lead to new ideas in the design of arc-generators which may considerably increase the efficiency. We shall, in the following, consider one such suggestion.

In all investigations referred to above, the arc always burned in a fairly homogeneous and symmetrical field so that the arc was exposed to the same field intensity along its entire path. If there was any variation, then the strongest field would be located where the arc is struck. The consequence of this is that the arc is accelerated quite rapidly immediately after it has been struck. The arc therefore only remains a very short time in the

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innermost position. This is a disadvantage insofar as the arc is shortest and would burn at the lowest possible voltage in this position. It is therefore desirable that this first part of the cycle be prolonged as much as possible. The arc voltage will then be very low during a considerable part of the period, during which interval a considerable part of the supply current is passing thru it. On the other hand, the arc must acquire the necessary speed toward the end of the period in order to develop the necessary extinction voltage or, in other words, the necessary peak-area.

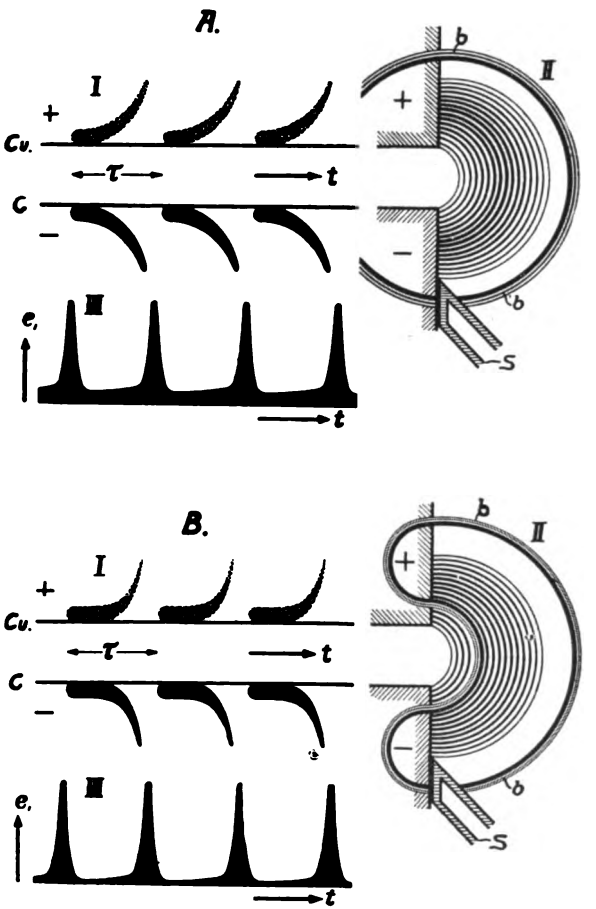

FIGURE 4—Schematic Representation of the Operation of the Arc:—*A* in a Homogeneous, and *B* in an Non-homogeneous Field. (The lines marked *b b* represent the boundary of the strongest part of the field.)

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The consequence of these considerations is that the field should not be homogeneous, but weaker near the ignition position of the arc and stronger near the position of extinction. This is shown schematically in Figure 4-B, while Figure 4-A shows a homogeneous field. Under the conditions shown in part *B*, the arc burns a comparatively long time near the starting point so that the arc voltage in a comparatively long time—as follows from what is set forth above—will be very low, and will not, until the end of the period, rise to the extinction value or develop the necessary peak-area (see part *B* III). The result is a low value of the burning voltage, and consequently also a low value of the supply voltage V_o, and therefore a high efficiency.

Even with ordinary circular pole pieces, this effect may be shown by placing the arc in the outskirts of the field, either as shown in Figure 5-A with the pole piece *P* over the cathode, in which case the cathode end of the arc is ignited in a comparatively weak magnetic field and extinguished in a comparatively strong field, or, as in Figure 5-B, with the pole piece over the anode,

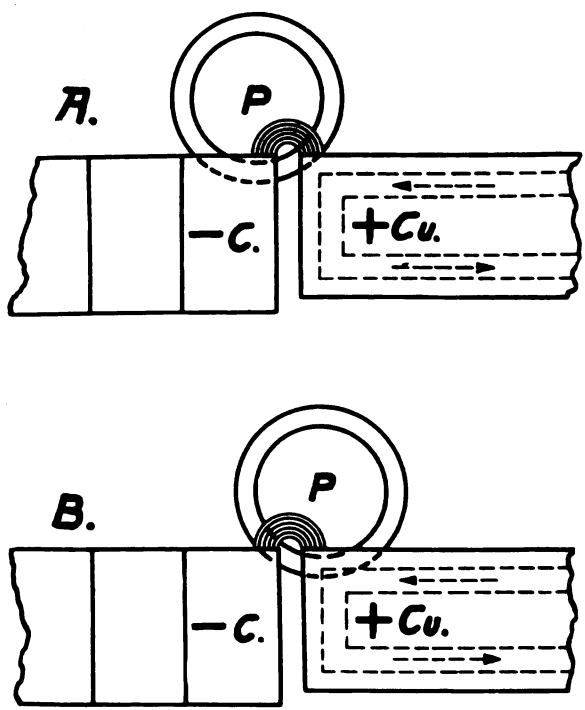

FIGURE 5—The Two Positions of the Arc in the Field of Circular Pole-pieces *P* referred to in Test 3 of the following table

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in which latter case it is the anode end of the arc which is ignited in the weaker and extinguished in the stronger field.

TABLE

WAVE LENGTH = 9,800 m. V_0 = ARC VOLTAGE

I_o = SUPPLY CURRENT I = RADIO FREQUENCY CURRENT = $\sqrt{\frac{1}{2}} I_o$

I_m = CURRENT THRU MAGNETIC COILS

Test	V_o	I_o	I_m	$H_{Gausses}$	Cooling Shoe[2]	Form of Field
1	280	56	0.5	790*	With Shoe	Non-homogeneous
	320	49	1.8	1,990	Without Shoe	Homogeneous
	296	58	0.5	790*	With Shoe	Non-homogeneous
2	284	56	0.5	790*	With Shoe	Non-homogeneous
	382	56	1.0	1,720	Without Shoe	Homogeneous
	284	56	0.5	790*	With Shoe	Non-homogeneous
3	270	56	0.75	970*	With Shoe	Non-homogeneous†
	270	56	0.5	870*	With Shoe	Non-homogeneous††
	360	56	1.85	1,700**	Without Shoe	Homogeneous

* Mean value of a field over the area covered by the arc.
** Shape of pole pieces different from that used in tests 1 and 2.
† Taken with arrangement B, Figure 5.
†† Taken with arrangement A, Figure 5.

The results of some tests made with the arrangements shown in Figure 5-A and B are recorded in the table. In order to eliminate any uncertainty with regard to the radio frequency losses, the value of the radio frequency current was in all measurements —except in test 1—adjusted to 40 amperes. (The ratio between I_o and I is always constant and equal to 0.71). With this method the efficiency in the various tests is simply inversely proportional to the applied voltages V_o. (Compare, for instance, paper (a), equation (2), page 263.)

In order to get the greatest possible efficiency, the position of the arc in the non-homogeneous field has to be rather exactly adjusted.

It appears that in both the cases presented in Figure 5, the efficiency can be increased from η to $1.25\,\eta$, η being the maximum efficiency obtainable in a homogeneous field. The maximum increase of η thru a practical application of the idea set forth in Figure 4-B has not yet been ascertained on large

[2] See paper (c).

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arcs, but must at all events be higher than the one stated above.[3]

In conclusion, I wish to acknowledge my indebtedness to Mr. J. P. Christensen for the excellent help he has given me in this work.

Royal Technical College, Copenhagen.

October, 1922.

SUMMARY: The possibility of increasing the efficiency of the Poulsen arc by burning it in a non-homogenous magnetic field is mathematically investigated, and experimentally verified.

[3] The correct distribution of the field intensity is of great importance in other ways, for instance, with regard to the regulation of the wear on the cathode carbon. In very large generators, this wear is often greatest at a certain distance from the edge of the carbon, and less at the edge itself. The reason for this is that the arc is not burning long enough at the edge, and when burning at that position is carrying too small a current. By making the field intensity smaller at the starting position of the arc, this irregularity may be eliminated. By suitable distribution of the field intensity any desired shape of the carbon tip may, no doubt, be obtained.

All these considerations make it desirable to have those parts of the pole pieces which cause the non-homogeneities in the field adjustable in such a way that the field distribution may be altered from outside the arc chamber.

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DISTORTION-FREE TELEPHONE RECEIVERS*

By

J. F. J. Bethenod

(Paris, France)

For many purposes, and in particular for radio telephonic reception, it is advantageous to obtain a distortion-free reproduction of speech and various sounds.

As is well known, the sensitiveness of telephone apparatus varies appreciably with the frequency of the current, that is, with the pitch of the sound being reproduced. The theory of this phenomenon has been set forth in the previous papers of Rayleigh, Kennelly, and others, and is based upon resonance between the impressed current frequency and the natural frequency of the diafram.

The object of the following article is to show how it is theoretically possible to realize a receiving system having a uniform sensitiveness over any range of frequencies required.

When a current i circulates thru the magnetizing coil, the centre of the diafram is displaced by an amount x which is determined by the equation:

$$A\,i = S\,x + R\frac{dx}{dt} + M\frac{d^2x}{dt^2}, \qquad (1)$$

in which A is the magnetic pull on the centre of the diafram for unit current, S, R, and M the stiffness, mechanical resistance, and equivalent mass of the diafram, respectively.[1]

In order to solve this equation, it is first necessary to obtain a second relation between i and x. Two cases are to be distinguished, depending on the manner in which is constituted the electric circuit comprising the magnetizing coil of the receiver.

1. The Electromotive Force Impressed on the Electric Circuit Has a Definite Value e

One may then write

$$e = Z\,i + A\frac{dx}{dt}, \qquad (2)$$

*Received by the Editor, January 17, 1923.

[1] See the above-mentioned works.

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in which Z is the impedance operator of the circuit. We will now ascertain the conditions which must be fulfilled in order to obtain a constant proportionality between x and e for a telephonic current of any frequency whatever. If we design the operation $\frac{d}{dt}$ by the symbol p, and introduce the abbreviation

$$P = S + p\,R + p^2 M \tag{3}$$

we obtain, from (1) and (2)

$$e = \frac{Z\,P\,x}{A} + p\,A\,x.$$

In order to solve the actual problem, the condition

$$x = \frac{e}{\lambda}, \tag{5}$$

must be satisfied, λ being a constant, positive or negative, which is quite independent of the current frequency. We thus obtain the relation

$$Z = \frac{\lambda A - p A^2}{P}. \tag{6}$$

Also, it must be remembered that the use of triodes, as proposed by Mr. Marius Latour in his French patent, number 501,472, of December, 1918, gives us the possibility of realizing artificial negative impedance, that is, not only negative resistances, but also negative inductances or capacities out of positive ones. Mr. L. B. Turner has since developed a negative resistance device by means of triode arrangements (Kallirotron). By means of these devices, it is therefore theoretically possible to neutralize the impedance z of the receiver winding (with diafram damped) and this for any current frequency. (Figure 1).

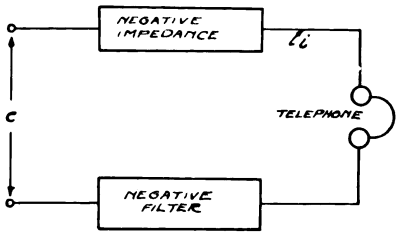

FIGURE 1

Furthermore, if we connect an inductance coil and a capacity in parallel, there results a joint impedance which is expressed by the well-known equation

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$$Z' = \frac{r+pl}{1+prc+p^2lc}, \tag{7}$$

in which l and r denote the inductance and ohmic resistance of the coil respectively, c, the capacity of the condenser (assumed without losses).

Now, if we make use of the device referred to above in order to reverse the sign of Z', that is, to constitute a "negative filter" which is inserted in the circuit, we obtain

$$Z = -g\frac{r+pl}{1+prc+p^2lc}, \tag{8}$$

the numerical factor g being positive.

A comparison of (6) and (8) gives the conditional relations

$$-\frac{\lambda A}{gr} = \frac{A^2p}{glp} = \frac{S}{1} = \frac{Mp^2}{lcp^2} = \frac{Rp}{rcp}, \tag{9}$$

from which it follows that

$$l = \frac{A^2}{gS}, \quad c = \frac{gM}{A^2}, \quad r = \frac{RA^2}{gMS}, \quad \lambda = -\frac{RA}{M}. \tag{10}$$

This method determines the quantities l, c, r, and λ.

Moreover, the equation (5) becomes

$$x = -\frac{M}{RA}e, \tag{11}$$

and the problem is theoretically solved.

2. The Telephonic Current Has a Definite Value I

From (1) we get, for a magnetizing current equal to i

$$x = \frac{Ai}{P}, \tag{12}$$

and the ratio $\frac{i}{I}$ will be chosen so that the new condition

$$x = \frac{I}{\mu}, \tag{13}$$

is fulfilled, μ being a constant, positive or negative, which is independent of the current frequency.

In order to arrive at this result, it is sufficient to shunt the receiver winding by means of a "negative resonator," utilizing the triode device previously referred to. (Figure 2.) The negative sign is thereby obtained and we may then put down

$$zi = -h\left(r+lp+\frac{1}{cp}\right)(I-i), \tag{14}$$

wherein h is a positive numerical factor.

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The condition to be fulfilled thus becomes

$$\frac{Px}{A} - = \frac{h\left(r+lp+\frac{1}{cp}\right)}{z-h\left(r+lp+\frac{1}{cp}\right)},$$

or

$$\frac{P}{A} = -\frac{\mu h\left(r+lp+\frac{1}{cp}\right)}{z-h\left(r+lp+\frac{1}{cp}\right)}. \qquad (15)$$

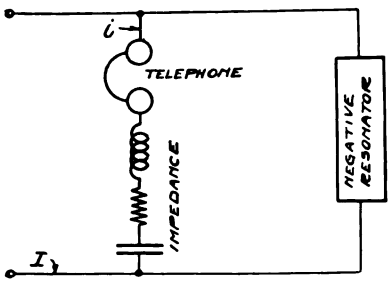

FIGURE 2

Furthermore, when connecting a positive resonator in series with the telephone winding (see Figure 2), we can always reduce the artificial impedance $z-h\left(r+lp+\frac{1}{cp}\right)$ to a pure capacitance $\frac{1}{kp}$. Consequently, the conditional equality (15) becomes

$$\frac{P}{A} = -\frac{\mu h k\,(1+prc+p^2lc)}{c},$$

or $$c\,(S+pR+p^2M) = -\mu hAk\,(1+prc+p^2lc),$$

whence follow

$$lc=\frac{M}{S}, \quad \frac{r}{c}=\frac{R}{M}, \quad \mu=-\frac{c}{k}\times\frac{S}{hA}, \text{ and so on.} \qquad (16)$$

Therefore, for any case, the natural frequency and the time constant of the diafram will be equal to the natural frequency and the time constant of the filter or resonator.

The above statements show sufficiently how it is theoretically possible to realize a telephone receiver the sensitiveness of which is independent of the impressed current frequency.

It is interesting to remark that, by means of the same arrange-

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ments, we may solve the theoretical problem of the distortion-free oscillographic or radio telegraphic recording apparatus.

SUMMARY: The possibilities of a distortion-free telephone receiver are discussed. By means of triode devices, it is theoretically possible to realize such apparatus having uniform sensitiveness over any range of frequency required. The same devices may be applied to oscillographic or radiotelegraphic apparatus.

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DIGESTS OF UNITED STATES PATENTS RELATING TO RADIO TELEGRAPHY AND TELEPHONY*

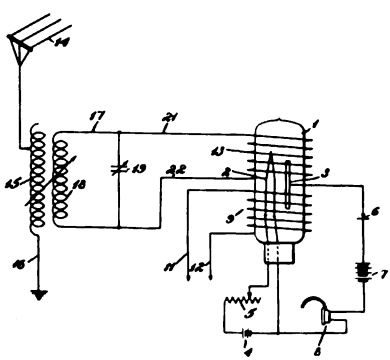
ISSUED DECEMBER 26, 1922—FEBRUARY 20, 1923

BY

JOHN B. BRADY

(PATENT LAWYER, OURAY BUILDING, WASHINGTON, D.C.)

1,440,432—C. T. Allcutt, filed June 25, 1921, issued January 2, 1923. Assigned to Westinghouse Electric and Manufacturing Company.



NUMBER 1,440,432—Radio Receiving System

RADIO RECEIVING SYSTEM, employing a two-electrode tube and a circuit arrangement for securing an interacting varying magnetic field produced by the interaction of the incoming signaling frequency and that of a local generator. The resultant magnetic field is transverse to the space current flow of the tube which is thereby controlled in accordance with the magnetic beat frequency to operate a telephone receiver.

1,440,834—C. V. Logwood, filed July 2, 1921, issued January 2, 1923. Assigned to De Forest Radio Telephone and Telegraph Company.

* Received by the Editor, March 7, 1923.

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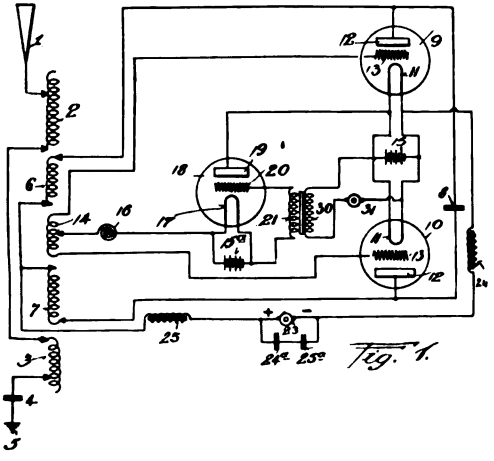

NUMBER 1,440,834—Electron Tube Transmitter

ELECTRON TUBE TRANSMITTER circuit having a plurality of electron tubes with their plate circuits connected with an antenna system. An additional tube is connected between the grid circuits of these tubes serving as an effective resistance in the first mentioned tube circuits. This effective resistance is varied in accordance with signals to control the output of the first mentioned tubes into the antenna system.

1,441,087—J. W. Hill, filed April 6, 1921, issued January 2, 1923.

WIRING SYSTEM, for improving sharpness in tuning in an electron tube transmitter. The tubes are all connected with equidistant leads from points in the circuits leading to similar elements of the tube whereby balancing of circuits is accurately obtained.

1,441,988—E. P. Lindner, filed December 18, 1920, issued January 9, 1923.

CRYSTAL DETECTOR construction wherein the crystal is supported in a cup mounted to rock about an axis to present the surface of the crystal to the rectifier contact point. A yieldable member is provided in the cup for maintaining the crystal in place.

1,442,146—R. A. Heising, filed April 13, 1918, issued January 16, 1923. Assigned to Western Electric Company, Incorporated.

MODULATING AND TRANSMITTING SYSTEM, employing electron

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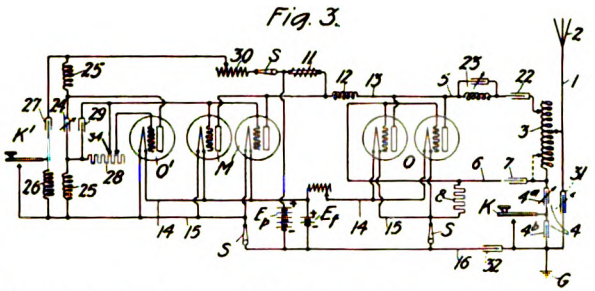
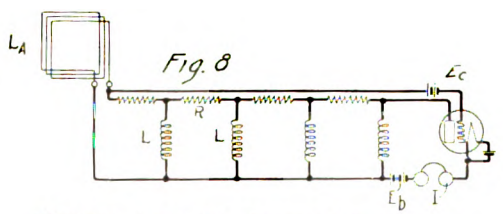
tubes in circuit with which a low frequency filter is located to prevent the radiation of low frequency hum with the modulated waves.



NUMBER 1,442,146—Modulating and Transmitting System

1,442,781—H. W. Nichols, filed July 7, 1921, issued January 16, 1923. Assigned to Western Electric Company, Incorporated.



NUMBER 1,442,781—Reamplifying System

REAMPLIFYING SYSTEM, in which an electron tube amplifier is provided with a feed-back connecting its output and input circuits, comprising a network having substantially capacitative reactance only. This arrangement selectivity amplifies energy of a particular frequency or range of frequencies without amplifying disturbing energy or other waves of considerably different frequency.

1,443,011—H. J. J. M. De R. De Bellescize, filed November 3, 1922, issued January 23, 1923.

ATMOSPHERIC DISTURBANCE REDUCING MEANS for a radio receiver comprising a resonant circuit with an amplifier connected to the circuit and a current limiting relay connected to the output amplifier with the detector and telephones connected to the output of the current limiting relay. The resonant circuit and the output of the current limiting relay are interconnected.

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whereby an electromotive force derived from the current limiting relay is impressed upon the resonant circuit opposing the flow of currents having a frequency equal to the natural frequency of the resonant circuit.

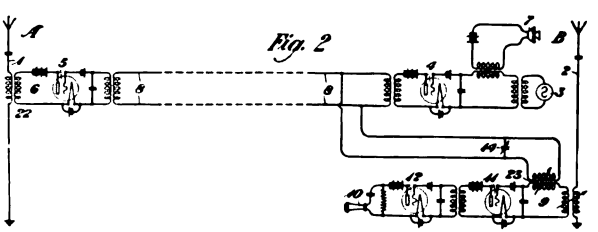
1,443,209—B. Bradbury, filed September 15, 1920, issued January 23, 1923. Assigned to General Electric Company, Incorporated.

RADIO RECEIVING SYSTEM, sharply tuned to eliminate the effects in the receiver of stations transmitting on closely adjacent wave lengths to the wave length desired to be received. A frequency trap is used in the telephone circuit. There are two portions to the frequency trap circuit, one of which is resonant to the signals of the frequency to be received and the other resonant to the frequency of interfering signals which it is desired to suppress.

1,443,361—J. H. Hammond, Jr., filed July 27, 1917, issued January 30, 1923.

SYSTEM FOR THE TRANSMISSION OF RADIANT ENERGY for secret communication. A set of rotatable commutators is provided at the transmitter in the keying circuit for impressing upon a source of oscillations periodic amplitude variations of relatively different frequencies with means for rendering either of said frequencies effective upon the oscillations. The receiver is provided with means for selectively receiving the modified signals.

1,443,985—L. Espenschied, filed June 21, 1919, issued February 6, 1923. Assigned to American Telephone and Telegraph Company, Incorporated.



NUMBER 1,443,985—Signaling System

SIGNALING SYSTEM for duplex operation, having a circuit for eliminating "side tone" at the receiver. The system employs carrier waves of different frequency for transmission and recep-

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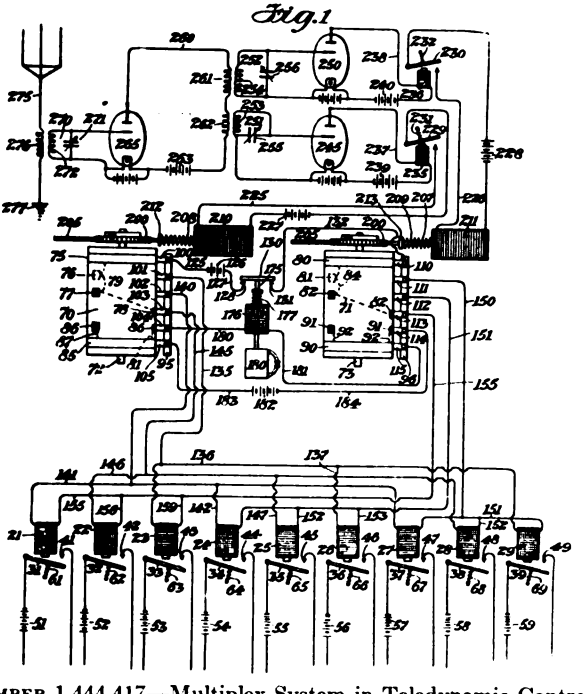
tion by providing separate antennas for transmitting and receiving, the said antennas being located a considerable distance from each other, and by neutralizing the inductive action of the transmitting system proper on the receiving system by means of balancing circuits. A conductive transmission line extends from the transmitting apparatus to the receiving apparatus, and a circuit is connected between this line and the transmitting and receiving apparatus for nullifying the effect on said receiving apparatus of the waves from the transmitting apparatus.

1,444,417—J. H. Hammond, Jr., filed October 17, 1917, issued February 6, 1923.



NUMBER 1,444,417—Multiplex System in Teledynamic Control

MULTIPLEX SYSTEM IN TELEDYNAMIC CONTROL for manipulating a plurality of separately operable devices selectively from a distance in response to radiant energy, and in which each of the controlled devices is arranged to be controlled by the conjoint action of a plurality of separately movable commutators or controlling elements which are in turn separately controlled rotatable step by step.

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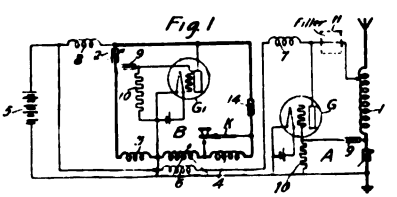
1,444,438—W. C. White, filed August 7, 1918, issued February 6, 1923. Assigned to General Electric Company, Incorporated.

GRID ELECTRODE STRUCTURE for an electron tube of the pliotron type. The difficulty of the grid wire turns becoming loose under conditions of unequal expansion and sliding down on the grid frame is prevented in this invention by a spiral wire coil on each side of the grid frame which space apart the turns of the grid and maintain the wires in spaced relation even under conditions of expansion.

1,444,534—B. Ames and P. J. Gilinson, filed February 15, 1918, issued February 6, 1923. Assigned to B. Ames.

ELECTRICAL CONDENSER, consisting of alternate layers of conducting material being somewhat longer than wide and the alternate layers of the conducting material disposed transversely of each other so as to project laterally on each side. A clamp for securing the condenser as a unit is held together at each corner of the device.

1,444,605—R. A. Heising, filed January 21, 1919, issued February 6, 1923. Assigned to Western Electric Company, Incorporated.



NUMBER 1,444,605—Carrier-Wave Signaling System

CARRIER-WAVE SIGNALING SYSTEM, comprising a high frequency generating system *A* and a low frequency generating system *B*. In system *A* high frequency oscillations are produced in the antenna circuit 1 by the action of the tube *G*. The frequency of the oscillations generated in the antenna is determined primarily by the tuning of the antenna. In system *B*, tube G_1 generates oscillations in a tuned circuit consisting of variable capacity 2 and inductances 3 and 4. Capacity 14 is included in the tuned circuit preventing the short circuiting of battery. A key *K* serves to short circuit a portion of inductance 4 for the purpose of changing the frequency generated in system *B*. By thus

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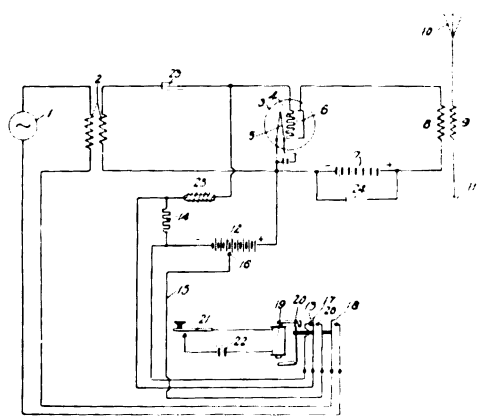
changing the frequency, signals may be transmitted. Current for the anode-cathode circuit of both tubes is furnished by the source 5. Coil 6 is variably coupled to coils 3 or 4, or both. Coil 7 constitutes a high impedance for currents of the frequency generated by the system *A*, and coil 8 constitutes a high impedance for currents of the frequency generated by the system *B*. The usual stopping condensers 9 and resistive leak paths 10 are provided. A filter or impedance device 11 of any suitable type, which may be a loop-resonant circuit tuned to the mean frequency of system *B*, prevents oscillations generated by the system *B* from being impressed upon the antenna circuit. During operation, the high frequency oscillations of the system *A* are modulated in accordance with the oscillations of the system *B*. This is caused by the intercoupling of coils 4 and 6, whereby a voltage corresponding to the low frequency oscillations is impressed upon the space between the anode and cathode of the tube *G*.

Re. 15,538—E. H. Colpitts, filed September 11, 1915, reissued February 13, 1923. Assigned to Western Electric Company, Incorporated.



Re. 15,538—Control Device for Radio Signaling

Control Device for Radio Signaling for modulating the output of an electron tube. The voltage of the battery in the input or grid circuit is made of such value that the space current, that is, the current in the output circuit, is made very small. Provision is made whereby the voltage applied to the grid or input circuit of the amplifier is changed at the instant of signaling

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from such a value as causes a minimum energy loss in the output circuit to a value which permits of normal flow of current in the said circuit whereby signal energy is radiated.

1,445,613—H. P. Donle, filed April 6, 1922, issued February 13, 1923. Assigned to The Connecticut Telephone and Electric Company, Incorporated.

DETECTOR, in which a sensitive crystal is placed in an evacuated tube and a granular contact provided. The tube is evacuated to avoid the possibility of deleterious action upon the sensitive portions of the detector by moisture, dust or fumes and oxidation which tend to reduce sensitivity.

1,445,636—A. Meissner, filed May 3, 1922, issued February 20, 1923.

METHOD OF AND MEANS FOR INDICATING THE FREQUENCY VARIATIONS OF AN ALTERNATING CURRENT, consisting of a circuit arrangement including an antenna and an alternating current generator connected with the antenna, a circuit coupled with the antenna, and an indicator connected in the circuit. A second circuit is also coupled with the antenna and having the current therein differing in phase by 90° from the current in the antenna. A third circuit is provided having the current therein differing in phase by 90° from the current in the second circuit. The second and third circuits are tuned to the desired frequency of the generator and the third circuit is coupled to the first mentioned circuit so as to transmit current thereto at a difference in phase of 180° from the current transmitted to said circuit by the first mentioned coupling. This causes the currents in the indicating circuit to compensate each other when the generator is supplying energy of the desired frequency.

1,445,929—W. R. G. Baker, filed October 7, 1920, issued February 20, 1923. Assigned to General Electric Company, Incorporated.

ELECTRON TUBE TRANSMITTER, including an oscillator and a modulator. When it is desired to change the output of the oscillator to increase the transmission range a circuit is provided wherein a single switch control with a pair of independent arms moving over independent contacts will vary the potential applied both to the plate circuit of the oscillator and to the grid circuit thereof.

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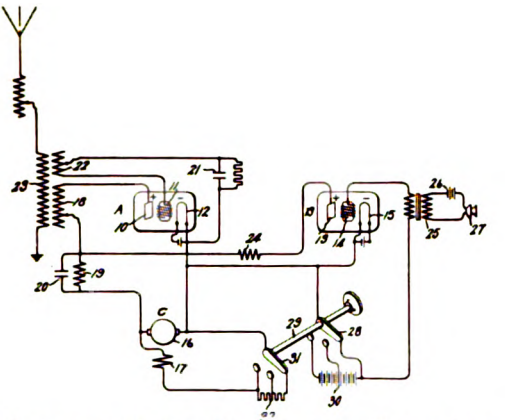

NUMBER 1,445,929—Electron Tube Transmitter

1,446,247—L. De Forest, filed March 16, 1921, issued February [redacted] 20, 1923.

LIGHT CONTROLLING MEANS comprising a tube entitled the "luxion." The tube contains mercury vapor or the like and a thermonic electrode therein with an anode spaced at some distance therefrom and connected in an external modulation circuit by which the relative intensity of the light extending between the electrodes may be varied. The device finds application in photography wherein light intensity may be controlled by voice frequencies and projected upon a film.

1,446,425—A. Leib, filed August 3, 1922, issued February 20, 1923.

WAVE METER WITH CATHODE TUBE, arranged to be coupled with an antenna system in circuit with a receiver. The tube is arranged in a self oscillatory circuit with a buzzer connected in the anode circuit for interrupting the current generated by the wave meter whereby the receiver may be calibrated from known calibrations of the wave meter circuit.

1,446,433—W. Schaffer, filed August 3, 1922, issued February 20, 1923.

CIRCUIT ARRANGEMENT FOR INDICATING THE DEVIATION OF A SENDER FROM A DESIRED FREQUENCY. The theory of this device which indicates when the transmitting wave length shifts from a desired value as follows: If two transmitters operate jointly at the same frequency on an oscillating circuit, a phase displacement of 180° occurs between them. The weaker of the

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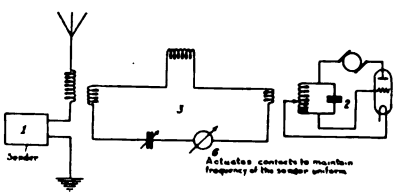
two transmitters is usually forced into or held in a 180° phase displacement by the more powerful transmitter. If the wave individual to the weaker sender is now slightly detuned with respect to the more powerful sender, the frequency of the oscillating wave does not vary, but apparently only the phase displacement of the two trasmitters with respect to each other is changed. Consequently, a measuring instrument provided in a circuit coupled with the two transmitters will register the variation. If, on the other hand, there is a variation in the wave of the more powerful sender, that is, the working sender, then this will have a corresponding effect on the auxiliary sender, the phase displacement being varied at the same time. The resulting variation in the current may then be used as a measure for the changes occurring in the wave, and the change in the output of the circuit may be used for correcting the occurring frequency variation. The present invention utilizes this theory by coupling an indicating device between a transmitting antenna system and a small oscillator and any deviation from the desired transmission wave is known by observing the indicator.



NUMBER 1,446,433—Circuit Arrangement for Indicating the Deviation of a Sender from a Desired Frequency

1,446,434—W. Schaffer and Dr. Fritz Kruschinsky, filed August 18, 1922, issued February 20, 1923.

CIRCUIT ARRANGEMENT FOR USE IN THE TRANSMISSION OF SIGNALS for supplying energy to electron tube circuits from an alternating current source for transmission. The invention relates to a particular combination of transformers, choke coil, and rectifier, connected to energize the tube circuits.

The following digests should be read in connection with those appearing in previous issues of THE PROCEEDINGS.

1,434,984—H. H. Beverage, filed May 3, 1921, issued November 7, 1922. Assigned to General Electric Company, Incorporated.

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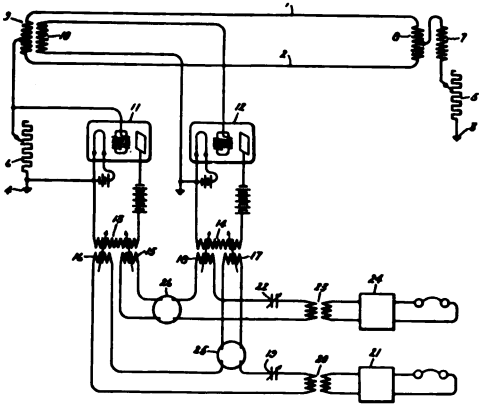
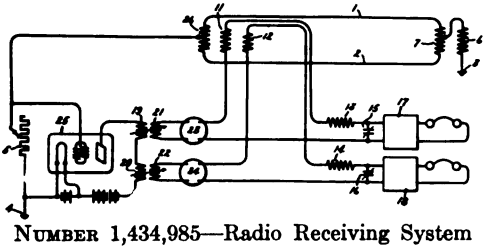


NUMBER 1,434,984—Radio Receiving System

RADIO RECEIVING SYSTEM for use with a Beverage antenna whereby signals may be simultaneously selectively received at the same receiving station from two different directions.

1,434,985—H. H. Beverage, filed May 3, 1921, issued November 7, 1922. Assigned to General Electric Company, Incorporated.



NUMBER 1,434,985—Radio Receiving System

RADIO RECEIVING SYSTEM, employing a Beverage antenna, for reception of a plurality of different wave lengths simultaneously. A plurality of receiving circuits which are resonant to the frequencies of the different signaling waves to be received are provided and the currents produced in the antenna at a selected point impressed upon these circuits. Each receiving circuit selects the particular signaling wave which it is desired to receive in that circuit without interfering with the selection of the desired waves by any of the other receiving circuits. In order to improve the reception, means are also provided for impressing upon each receiving circuit a current selected from

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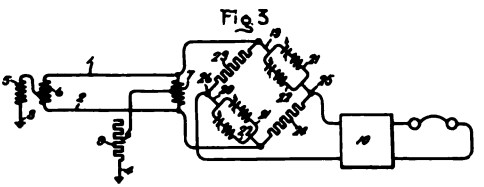
another point in the antenna which will be of the proper intensity and phase to neutralize in each receiving circuit disturbing currents produced therein either by interference from undesired waves or by strays.

1,434,986—H. H. Beverage, filed May 25, 1921, issued November 7, 1922.



NUMBER 1,434,986—Radio Receiving System

RADIO RECEIVING SYSTEM, employing a Beverage antenna in which a balanced bridge circuit is provided for preventing interference in the system by waves of a wave length approximately the same as the wave length desired to be received and which are traveling in the same direction as the waves desired to be received.

LIST OF RADIO TRADE MARKS PUBLISHED BY PATENT OFFICE PRIOR TO REGISTRATION

The numbers given are serial numbers of pending applications:

159,955—"RADIOHOME" for radio apparatus. De Forest Radio Telephone and Telegraph Company, New York. Claims use since January 12, 1922. Published January 9, 1923.

168,098—"AUDIOPHONE" for loud speakers. The Bristol Company, Waterbury, Connecticut. Claims use since July, 1922. Published January 9, 1923.

170,131—"WAVOLA" for radio apparatus. The Fairmount Electric and Mfg. Co., Philadelphia, Pennsylvania. Claims use since about August 14, 1922. Published January 9, 1923.

170,478—Representation of head with ears of exaggerated size, for radio receiving apparatus. The Dyer Company, Cambridge, Massachusetts. Claims use since September 1, 1922. Published January 9, 1923.

170,969—"THE EAR OF THE WORLD"—design of world with ear

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in center of globe and receiving set in foreground—for radio apparatus. Chicago Radio Laboratory, Chicago, Illinois. Claims use since about February, 1922. Published January 9, 1923.

166,405—"RESCO RADIO" for radio receiving apparatus. The Radio Engineering and Sales Company, doing business as The Resco Radio Company, Cleveland, Ohio. Claims use since May 1, 1922. Published January 16, 1923.

168,000—"GO SKYLARKING WITH THE SKYLARK" for radio receiving apparatus. The Perry, Desjardins and Temple Company, Cincinnati, Ohio, assigned to The Skylark Radio Company, Cincinnati, Ohio. Claims use since June 23, 1922. Published January 23, 1923.

169,572—"ARECO" for radio sets and parts thereof. American Radio and Electric Company, New York, N. Y. Claims use since February 2, 1922. Published January 23, 1923.

171,109—"TUSKA RADIO" in ornamental arrangement, for radio apparatus. The C. D. Tuska Company, Hartford, Connecticut. Claims use since July 24, 1922. Published January 23, 1923.

168,093—"RADION" dials made of hard rubber for radio apparatus. American Hard Rubber Company, Hempstead and New York, N. Y. Claims use since April 14, 1922. Published January 23, 1923.

169,184—"RADIOGEM" for radio tuning coil. Radiogem Corporation, New York, N. Y. Claims use since August 21, 1922. Published January 30, 1923.

169,824—"RCA" in ornamental arrangement for radio receiving and transmitting apparatus. Radio Corporation of America, New York, N. Y. Claims use since August 15, 1922. Published January 30, 1923.

170,476—"CROSLEY" for radio receiving apparatus. The American Automobile Accessories Company, doing business as Crosley Mfg. Company, Cincinnati, Ohio. Claims use since July 15, 1922. Published January 30, 1923.

170,529—"RADIO ROSE" for radio receiving apparatus. Jackson and Finkenaur, New York, N. Y. Claims use since September 27, 1922. Published January 30, 1923.

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... radio receiving sets. Oard Radio ... business as Atlantic-Pacific Radio Sup... Stockton, California. Claims use since May ... published January 30, 1923.

... in ornamental design, for radio cabinets. The ... Works, Indianapolis, Indiana. Claims use since 1890. ... 30, 1923.

... "SKYLARK" for radio receiving apparatus. The Perry, Desjardines and Temple Company, Cincinnati, Ohio. Assigned to The Skylark Radio Co., Cincinnati, Ohio. Claims use since June 23, 1922. Published February 6, 1923.

169,208—"SENSORY" in ornamental design, for radio receiving apparatus. Heinemann Electric Company, Philadelphia, Pennsylvania. Published February 6, 1923.

169,855—"BESTONE" dials for tuning apparatus. Henry Hyman and Company, Incorporated, New York, N. Y. Claims use since April, 1922. Published February 6, 1923.

165,699—Mark represents an ear cap for a telephone receiver with the diafram colored in red and showing thru the cap. For head telephone receivers. Metropolitan Radio Corporation, Newark, New Jersey. Claims use since June 1, 1922. Published February 13, 1923.

169,134—Letter "M" upon a seal with ornamental lightning flash behind the seal. For radio and electrical apparatus. Manhattan Electrical Supply Company, Incorporated, New York, N. Y. Claims use since April 10, 1922. Published February 13, 1923.

171,797—"SIMPLE RADIO-PHONE" assembled with design of antenna ground system, for radio receiving apparatus. A. W. Hanington and Sons, New York, N. Y. Claims use since June 15, 1922. Published February 13, 1923.

165,533—"DIXIE" for radio receiving sets. Edwards and Company, Incorporated, New York, N. Y. Claims use since May 9, 1922. Published February 20, 1923.

165,968—"RADO" in ornamental design, for radio apparatus. The Ra-Do Corporation, Bay City, Michigan. Claims use since May 9, 1922. Published February 20, 1923.

169,869—"RASCO" for radio apparatus. Radio Specialty Com-

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pany, New York, N. Y. Claims use since April, 1921. Published February 20, 1923.

169,909—"R. P. C." for radio receiving apparatus. Chas. M. Kemper, doing business as Radio Products Company, Westport, Connecticut. Claims use since September 8, 1922. Published February 20, 1923.

171,543—"CLAROPHONE" for loud speakers. Master Radio Corporation, Los Angeles, California. Claims use since August 10, 1922. Published February 20, 1923.

171,670—"MASTER" in shield design, for radio receiving and transmitting apparatus. Union Construction Company, San Francisco, California. Claims use since May 15, 1922. Published February 20, 1923.

171,671—"MASTROLA" in ornamental design, for radio receiving sets. Union Construction Company, San Francisco, California. Claims use since May 15, 1922. Published February 20, 1923.

172,137—"VICT-RA-PHONE" for radio receiving apparatus. Victor Radio Corporation, New York, N. Y. Claims use since May 1, 1922. Published February 20, 1923.

172,424—"DUOTROL" for rheostats. Malone-Lemmon Laboratories, New York, N. Y. Claims use since about May, 1922. Published February 20, 1923.

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PROCEEDINGS OF
The Institute of Radio Engineers

Volume 11 JUNE, 1923 Number 3

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RECEIVING MEASUREMENTS AND ATMOSPHERIC DISTURBANCES AT THE UNITED STATES NAVAL RADIO RESEARCH LABORATORY, BUREAU OF STANDARDS, WASHINGTON, JANUARY AND FEBRUARY, 1923*

By

L. W. Austin

(United States Naval Radio Research Laboratory, Washington, D. C.)

(*Communication from the International Union for Scientific Radio Telegraphy*)

The observations for January and February show the continuation of winter conditions. The afternoon signals and disturbances are, in general, slightly stronger than those of the forenoon, and the disturbances are uniformly weak. Lafayette was not heard during the forenoon in January, but has been measured a number of times in February.

The calculated signal intensities, assuming 480 amperes at Lafayette and 380 amperes at Nauen are:

$$E \text{ (Lafayette)} = 31.5 \cdot 10^{-6} \text{ volts/meter}$$
$$E \text{ (Nauen)} = 15.31 \cdot 0^{-6} \text{ volts/meter}$$

Ratio of Averages

	Signal P. M. / A. M.	Disturbance P. M. / A. M.	A. M. Signal / Disturbance	P. M. Signal / Disturbance
	January			
$\lambda = 23{,}400$ m.	....	1.32	....	3.86
$\lambda = 12{,}500$ m.	1.33	1.24	2.37	2.53
	February			
$\lambda = 23{,}400$ m.	1.15	1.65	6.85	4.94
$\lambda = 12{,}500$ m.	1.24	1.82	3.76	2.58

*Received by the Editor, March 30, 1923.

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FIELD INTENSITY OF LAFAYETTE AND OF DISTURBANCES
($\lambda = 23{,}400$ m.) IN JANUARY, 1923, IN MICRO-VOLTS PER METER

	10 A. M.		3 P. M.	
Date	Signal	Disturbances	Signal	Disturbances
2	*	10	90.0	42
3	*	35	100.0	60
4	*	28	95.0	35
5	*	12	100.0	21
6	*	16	165.0	15
8	*	28	105.0	15
9	*	6	125.0	15
10	*	10	125.0	20
11	*	14	85.0	25
12	*	18	100.0	15
13	*	33	....	..
15	*	20	85.0	25
16	*	15	....	..
17	*	8.4	75.0	20
18	*	20	105.0	16
19	*	8	110.0	50
20	*	15	55.0	10
22	*	28	....	..
23	*	40	75.0	40
24	*	10	90.0	40
25	*	23	75.0	15
26	*	28	115.0	21
27	*	19	100.0	40
29	*	21	100.0	16
30	*	15	90.0	10
31	*	18	100.0	18
Average	*	19.2	98.5	25.4

*Not heard.
....Not taken.

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FIELD INTENSITY OF LAFAYETTE AND OF DISTURBANCES ($\lambda = 23{,}400$ m.) IN FEBRUARY, 1923, IN MICRO-VOLTS PER METER

	10 A. M.		3 P. M.	
Date	Signal	Disturbances	Signal	Disturbances
1	*	10	95.0	16
2	*	15	80.0	19
3	*	19	*	25
5	*	8	90.0	18
6	70.0	12	100.0	10
7	*	8	95.0	15
8	*	..	90.0	16
9	*	10	80.0	15
10	*	18	*	9.3
12	95.0	32	90.0	20
13	*	8	*	16
14	80.0	10	95.0	21
15	75.0	17	75.0	18
16	85.0	11	80.0	12
17	100.0	8	105.0	12
19	*	6	*	15
20	*	4	*	18
21	95.0	4	90.0	10
23	80.0	12	100.0	9
24	70.0	10	....	..
26	65.0	6	120.0	80
27	90.0	22	125.0	50
28	90.0	16	120.0	16
Average	82.9	12.1	95.8	20

*Not heard.
....Not taken.

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FIELD INTENSITY OF NAUEN AND OF DISTURBANCES ($\lambda = 12{,}500$ m.) IN JANUARY, 1923, IN MICRO-VOLTS PER METER

	10 A. M.		3 P. M.	
Date	Signal	Disturbances	Signal	Disturbances
2	9.0	8	26.5	19
3	25.2	15	18.5	20
4	27.8	12	17.0	15
5	*	6	19.0	10
6	17.0	8	25.0	8
8	21.5	16	34.0	8
9	*	4	43.0	8
10	22.8	6	34.0	10
11	30.0	8	38.5	12
12	13.0	18	43.0	6
13	25.0	15	....	..
15	25.7	4	22.8	10
16	17.0	8	....	..
17	25.0	5.2	30.0	10
18	13.6	6	34.0	8
19	25.7	8	18.0	18
20	10.5	5	14.0	4
22	21.5	16	....	..
23	*	15	28.0	22
24	32.5	6	25.0	23
25	22.1	12	43.0	6
26	17.5	10	43.0	8
27	19.2	8	39.5	22
29	35.5	10	27.0	8
30	26.0	8	32.5	4
31	29.0	6	25.0	10
Average	22.3	9.4	29.6	11.7

*Not heard.
....Not taken.

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FIELD INTENSITY OF NAUEN AND OF DISTURBANCES ($\lambda = 12{,}500$ m.) IN FEBRUARY, 1923, IN MICRO-VOLTS PER METER

	10 A. M.		3 P. M.	
Date	Signal	Disturbances	Signal	Disturbances
1	5.4	4	14.5	8
2	17.5	6	22.9	6
3	12.0	15	21.5	18
5	14.0	3	25.0	10
6	17.5	6	22.9	4
7	43.0	4	27.0	8
8	35.5	5	32.5	9
9	27.0	6	47.0	8
10	30.0	10	33.3	5.6
12	17.0	15	30.8	8
13	17.5	4	43.0	8
14	19.2	4	34.8	10
15	*	6	17.0	9
16	22.1	5	20.5	6
17	13.8	3	22.8	4
19	17.0	3.1	22.1	8
20	25.8	2	22.8	6
21	24.0	1.2	23.5	4
23	25.2	6	22.8	3
24	20.0	6	....	..
26	19.0	3	22.1	62
27	*	6.3	22.8	10
Average	21.1	5.6	26.3	10.2

*Not heard.
....Not taken.

SUMMARY: Field intensities of the signals from the Lafayette and Nauen stations, together with the simultaneous strength of the atmospheric disturbances are given for January and February, 1923.

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RADIO EXTENSION OF THE TELEPHONE SYSTEM TO SHIPS AT SEA*

By

H. W. Nichols

(Western Electric Company, New York)

and

Lloyd Espenschied

(American Telephone and Telegraph Company, New York)

In 1919, the American Telephone and Telegraph Company and the Western Electric Company initiated a development program which had for its object the development of a radio telephone system capable of enabling the service of the Bell Telephone System to be extended to include vessels at sea. The program involved extensive development work in the laboratory and field, the establishment of shore and ship stations, and the putting of the system into practical operation, altho on a limited and experimental scale.

It is the purpose of this paper to describe the results of this development work from the standpoint of the complete system, with emphasis upon the general transmission and operating features rather than upon the details of the apparatus developed to perform the necessary functions. The development divides itself, naturally, into two parts: first, the determination of the system-design and the establishment of the necessary stations, and, second, the study of the transmission and operating characteristics of the system.

PART I

RADIO SYSTEM-DESIGN AND ESTABLISHMENT OF STATIONS

General Plans

The fundamental condition laid down at the beginning of this work was the very general one that there should be developed a system by which any telephone subscriber of the Bell System

*Presented before The Institute of Radio Engineers, New York, January 3, 1923. Received by the Editor, January 4, 1923

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could carry on a conversation with a telephone station located on a ship, and that, from the point of view of the speakers, the operation should be similar to the carrying on of an ordinary toll call between land wire subscribers. This, of course, involves the development of a satisfactory two-way radio telephone system for ship use. Furthermore, it was desired to be able to carry on three simultaneous and independent conversations between three ships and one land station, since a final commercial system will involve the establishment of several circuits simultaneously. These 2-way transmissions were to be obtained without employing an excessively large frequency band.

A rough study of the problem resulted in a decision to locate the experimental land stations about 200 or 250 miles (320 or 400 km.) apart and to try for reliable commercial transmission to ships at a distance of approximately 200 miles (320 km.).

The transmission problems involved in this work, which were different from those in wire telephone engineering, were:

(a) A much greater variability in the transmission equivalent to be expected in the radio link;

(b) A much greater and more variable interference, both natural and artificial;

(c) A lack of secrecy in the sense of a wire system;

(d) Greater possibilities of cross-talk between channels because of the use of a single medium;

(e) More complication in the matter of signaling and in the setting up of the telephone circuit.

The apparatus problems were, of course, entirely different from those of wire transmission and will not be considered in detail in this paper.

An engineering project of this kind divides itself naturally into two phases; that of the development in the laboratory of systems and apparatus which are technically suitable for the work and, second, the providing in the field of a model system, incorporating the knowledge obtained in the laboratory as a means for enabling the system to be tried out. A preliminary survey of the purely technical problems convinced us that the more important ones were the development of two-way radio telephone apparatus and of multi-channel systems which would operate from a single transmitting station without interference between channels; the design of transmitting apparatus which would satisfy the requirements and which could be built with the vacuum tubes available, and the development of a type of

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receiving system which would provide sufficient selectivity to allow an economical use of the frequency range and at the same time fit in with the two-way system most likely to be adopted. It was decided that during the laboratory development work preparations should be made in the field for providing the necessary experimental stations. This field work as it developed included the location of station sites, the actual construction of the station buildings and the antennas, the equipping of the stations with the apparatus as developed in the laboratory and as further developed in the station, the equipment of the ships, and, finally, the operation and tests of the overall system.

System Design Considerations

In the beginning it was thought that to cover the required 200 miles (320 km.) range about one or one and one-half kilowatts in the antenna would be necessary. It was not known what wave lengths would be made available for this work by the Department of Commerce. To produce this amount of power in the antenna there were available Western Electric 250 watt tubes which it was decided to employ. The question then arose as to the particular type of transmission systems most suitable for the work. The points of importance in solving this problem are as follows:

The greatest economy both in power and in wave length range may be secured by transmitting only one side band of the modulated wave. Moreover, this method has the great advantage that variations in the transmission characteristics of the medium do not cause as great fluctuations in the received signal. This is because the received signal is proportional to the product of the carrier and side bands and if the carrier is supplied locally instead of being transmitted, it is not affected by transmission factors. The use of such a system, however, or of one in which only the carrier is suppressed, throws upon the receiving set the burden of maintaining a constant oscillator frequency not only complicating it but also making reception impossible for the great majority of ships which are equipped with only straight detectors. This would defeat general inter-communication in emergency. Further, it practically restricts the transmitting set to one in which the power tubes are used as amplifiers, and it was known that some difficulty might be experienced in operating a number of 250 watt tubes in parallel if it should be necessary to transmit at wave lengths as low as 300 meters. For these reasons and after some development work it was decided that the proper

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system to use in the first experiment was one in which modulation is carried on by the constant current method which requires about an equal number of modulator tubes and power tubes and sends out all components of the modulated wave.

The simultaneous transmission of three channels from the land station may be accomplished in several ways. It is possible, for example, to carry on such multi-channel operation from one antenna, which is multi-tuned, or from three separate antennas. The antenna power may be supplied by one system of tubes carrying all three conversations or the power tube system may be split into three parts. Also, using a single antenna simply tuned it would be possible to transmit the three channels from one system of tubes by a system of double modulation which had been installed by the Western Electric Company on United States battleships two or three years earlier. The difficulties which are likely to arise in these various schemes are as follows: The use of multi-tuned antennas involves loss of power in the circuits used to give the antenna three degrees of freedom. The use of a single system of power tubes for three channels requires that the tube system be capable of handling a large overload at times without impairment of quality, since it is possible that the peaks of three channels may occur simultaneously. It was expected that under conditions of this kind there would be inter-modulation of the channels due to the modulating action in the plate circuits of the power tubes. The use of three separate antennas located very close to one another and tuned to frequencies differing by three or four percent. might lead to such close coupling of the three channels that cross-talk and modulation of one channel by another would result, the latter by plate modulation of one set of tubes by the currents induced in its antenna. The use of the double modulation system—altho requiring but one radiated carrier—is open to the objection of overloading and cross modulating of channels and also to the objection that the receiving apparatus aboard ship must be more complicated. An analysis of these and other proposed methods of operation resulted in the decision to employ at that time three separate but closely adjacent antennas and three separate transmitting sets using the constant current modulation system. This choice was made because of conditions peculiar to this particular problem and to the vacuum tubes then available. Of course improvements can be made in the system at the present time as a result of the information obtained in the development using the very much larger vacuum tubes now available.

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These decisions, therefore, determined the general type of system to be used, namely, one in which many of the known advantages of single side band transmission were sacrificed in order to secure simple apparatus, to make use of then existing power tubes, and to enable the transmission to be received generally.

The problem of securing the two-way operation necessary aboard ship and for combined radio and wire operation may be attacked in several ways. In general, there are three methods available:

(1) In which the east and west channels are established alternately and not simultaneously, by switching. The push-button scheme is a familiar example, although unsuitable for tying in with the wire telephone system. Another arrangement is the use of voice-operated relays to throw the terminal apparatus into the sending or receiving condition, depending upon the direction of transmission.

(2) The use of the principle of balance to separate the outgoing from the received transmission. The radio receiving antenna circuit is balanced with respect to the transmitting antenna circuit.

(3) Employment of different frequencies for the two transmissions, relying upon frequency-selecting circuits for effecting separation. The first two methods allow of operation on the same or on different carrier frequencies.

All of these fundamental methods were considered in their several possible embodiments, and compared from the standpoint of the conditions to be met in the radio system itself and in linking it with a public service telephone system. The system finally adopted employed different frequencies for sending and receiving and secured discrimination by frequency selection supplemented at the land station by a moderate degree of spatial separation and balance. By using sharply selective receiving circuits, a moderate frequency difference between east and west channels sufficed to give the necessary degree of separation.

Preliminary Tests

By the time these decisions had been made there was available for experimental purposes a plot of land near Cliffwood, New Jersey. It was decided to construct a model of the proposed antenna system on this plot and to operate small transmitting

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sets to determine the cross-talk and other important conditions. The antenna system decided upon consisted of three poles arranged in the form of an equilateral triangle supporting three antennas—one from the middle of each span to the transmitting shack at the center of the triangle. The dimensions of this model system were 50 meters (164 ft.) by 10 meters (33 ft.) high. Three experimental transmitting sets of small power were set up under the antenna system and studies were made of the interference produce between channels when all three channels were in use. Three receiving sets of the general form proposed were built and taken to a location near Elberon, New Jersey, about 16 miles (26 km.) from Cliffwood, at which place it was decided to locate the three-channel receiving station to co-operate with the New Jersey transmitting station a mile (1.6 km.) away.

In November, 1919 the first test of a three-channel system was held between Cliffwood and Elberon with the result that the receiving sets resolved conversations on carriers of frequencies of 725, 750, and 775 kilocycles without any cross-talk altho the received volume was so large as to be audible all over the room. This is a frequency difference between channels of approximately three percent. A change in frequency to 747, 759, and 777 kilocycles resulted in a barely perceptible cross-talk on the middle channel, with no cross-talk on the others. These results indicated that the loop receivers which had been developed were sufficiently sensitive and selective to carry out the proposed three-channel work; and, altho a great deal of development work was done later on the receiving sets, the general principles were retained. It was found that some reliance must be placed upon the directional properties of the loop antennas, and considerable care was used to secure very sharp directional selectivity. This was done by compensating for the vertical antenna effect of the loop by a balanced connection to ground.

During the whole course of this ship-to-shore work very little trouble was experienced thru interference by continuous wave stations, even when their frequencies came within two or three percent of those to be received. We did have, however, much difficulty due to interference from spark stations, since they inherently occupy a wide frequency range.

Provision of Stations and Development of Apparatus

During the time the model system was being constructed at Cliffwood, land had been purchased at West Deal, Monmouth County, New Jersey, for the permanent transmitting station.

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It contains about sixty-three acres in the general form of a square bisected by a small brook flowing east. The center of this site is 1.1 miles (1.8 km.) south of the Elberon receiving station.

In the spring of 1919, six 165 foot (30 m.) self-supporting steel towers had been ordered, three of which were intended for the Deal Beach station and three for the Green Harbor station to be built near that town in Massachusetts. Following preliminary work at Cliffwood it was decided to erect these steel towers in the form of an equilateral triangle five hundred feet on a side. This work was completed by December, 1919.

In the meantime, complete building plans had been made and contracts awarded for building the permanent transmitting station. On account of severe weather conditions and strikes, the construction of the building was delayed, so that in order to carry on experimental work a small frame building was constructed under the antenna system. It was decided to build in this temporary building a rough transmitting set which could be used as a model in the final design of the four sets to be located in the permanent building. This method of handling the work turned out to be much better than attempting to design the whole transmitting set on paper, because with these rather short wave lengths some troubles were experienced by the setting up of very short wave oscillations in the wiring of the set. Some experimental work was necessary to obtain the proper layout of circuits connecting the various parts of the apparatus.

At about this time antenna studies were made to determine the proper form to give to antenna suitable for three-channel operation without excessive cross-talk and this study indicated that by the use of series inductance and capacity the antennas could be stiffened enough to prevent excessive coupling effects and still pass the required frequency band.

The experimental transmitter was completed in February 1920 and in the middle of that month speech was transmitted from Deal Beach to New York and sent from there over wire lines for test purposes.

The spring was spent in study and improvement of the transmitter circuits, and in April the design and construction of the final model, of which set four were to be built, began. This transmitter was completed by May and later, in June, was sent to Green Harbor, Massachusetts, in order that the latter station might be available for test purposes.

Work now began on the four final transmitters for the Deal Beach Station. These sets were manufactured in the New York

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shop from working drawings made from the experimental model.

The final transmitting apparatus being well on the way, tests of the model transmitting set were made prior to its removal to Green Harbor, to determine the transmission characteristics and the distances which it might be expected to cover. In order to do this a systematic program of broadcasting music and speech from Deal Beach Station began in May, 1920. Amateurs and others were requested to co-operate with us in the study of "fading" and other transmission phenomena. As a result of these tests many hundreds of letters were received, which showed that audible radio signals were often received at a distance of one thousand miles (1,600 km.), altho a great deal of fading was to be expected, in overland transmission at least, even at moderate distances. These tests were carried on at wave lengths in the neighborhood of 400 meters.

While this work was going on, a two-way telephone set for use aboard ships was developed, and in the spring of 1920 one of these sets was installed aboard the steamship "Ontario" of the Merchants and Miners Transportation Company. Experimental communication with this ship, by means of the model transmitters at both Deal Beach and Green Harbor stations, showed that commercial operation, at least for one channel, could be maintained.

By the fall of 1920, the construction work on the four transmitting and receiving channels was completed and early in December a demonstration of simultaneous three-channel operation from this station to ships was carried out with entirely satisfactory results.

Description of the Experimental Radio Stations

The system as developed at Deal Beach consists of four transmitting sets, operating into four separate, altho naturally coupled, antennas, one set and antenna being intended primarily for 600 meter calling and for emergency. The receiving station co-operating with Deal Beach is located about a mile (1.6 km.) north of that station and contains four receiving sets receiving energy from four loop antennas. The transmitting sets are capable of putting about one kilowatt of modulated radio frequency power into each antenna and are controlled from a telephone switchboard into which run trunk lines from New York City. A ten-pair telephone cable connects Deal Beach and Elberon and another telephone switchboard at Elberon permits the transfer of received signals back to the wire line. The radio

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station operates, therefore, generally as a telephone repeater arranged for two-way operation with two repeaters. At the ship stations, because of the small amount of space involved, transmitting and receiving are carried on the same antenna at different frequencies in the two directions. Because of the better receiving conditions on the shore the proper transmission balance was obtained by making the output of the ship transmitting set about one-quarter that of the land station.

The general principle of operation of one channel of the wire-to-radio repeater will be described from the schematic circuit diagram of Figure 1, which shows, in the dotted blocks, one channel of the transmitting station, a ship station, and one receiving set. At the transmitter station the master oscillator, very carefully shielded to maintain constant frequency, operates into a two-stage amplifier, the last stage being fifty watt tubes, and from there into a bank of six radio frequency power tubes, each with a rating of 250 watts plate dissipation. Speech to modulate this radio frequency output enters from a telephone line and is applied to a speech amplifier the output of which operates into a bank of 250 watt modulator tubes in parallel. Thus both the radio frequency and the speech frequency currents are brought up to the high power level before modulation takes place. The six radio frequency and six speech frequency tubes have their plate circuits connected together and operate as a constant current modulation system. Thus current of the frequency F_1, generated by the master oscillator and amplified and modulated, is radiated from the antenna. The notation $F_1 \pm S_1$ indicates the radiation of the carrier and two side bands from this antenna. The incoming speech S_1, as it comes from the telephone line, passes thru the hybrid coil and to the balancing network shown. This balancing network has an impedance characteristic similar to that of the incoming line, and the combination of hybrid coil and network is similar to that used in telephone repeater practice to secure two-way operation. The object of this arrangement is, of course, to prevent signals, coming in from the receiving station, operating upon the transmitter of the outgoing channel. If the balancing network is an exact picture of the incoming line and if the hybrid coil is properly made, incoming signals for transmission west on the telephone line will produce no voltage at the terminals of the transmitting amplifier.

At the receiving station the incoming wave is impressed upon a loop antenna and the receiving set. The resulting detected

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[illegible] amplified as indicated and returns to the hybrid [illegible] going out on the telephone line without producing a volt- [illegible] the speech amplifier of the transmitting set if the hybrid [illegible] coil is perfect.

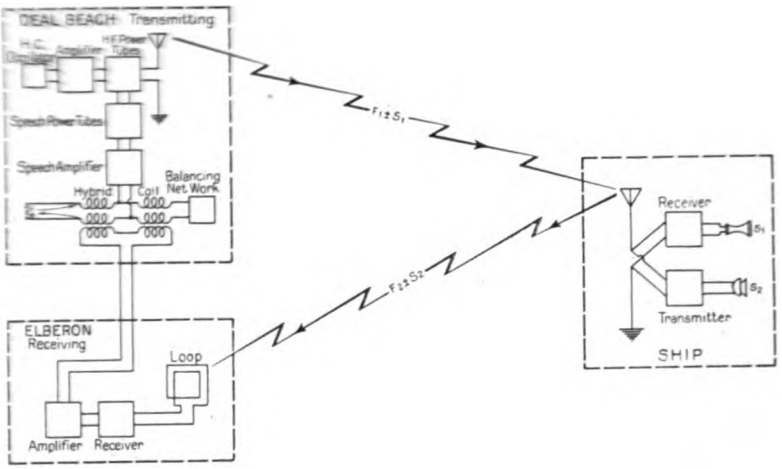

FIGURE 1—Two-way Radio-Wire System

On the ship, this physical separation of transmitting and receiving set is, of course, not practical, and, as indicated before, transmission and reception take place upon one antenna so arranged that the receiving circuit offers a high impedance to currents of the outgoing frequency and low impedance to the incoming signal. Actually, the outgoing signal is not entirely excluded from the ship's receiver and there is present a side tone of about the magnitude of the incoming signal. This is by no means an undesirable condition and is the one which holds approximately in an ordinary telephone subscriber's instrument. The presence of side tone assures the speaker that his system is functioning properly.

Figure 2 shows a general view of the outside of the transmitting station at Deal Beach. The three steel towers form an equilateral triangle of sides five hundred feet (150 m.) and each is one hundred and sixty-five feet (50 m.) high. Steel cables to support the antennas are strung between these towers and also three cables extending inward support a fourth antenna which rises directly from the building in the middle of the triangle. One antenna goes to the middle of each of the first mentioned

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steel cables, so that there are a total of four transmitting antennas. One of these is intended for use at six hundred meters. The building is thirty by ninety feet (9.1 by 27.3 m.) and two stories high. The southern half comprises the operating room which rises two full stories. The other part of the building is taken up by an office, shop, power room, living and dining room and kitchen, and by six bedrooms.

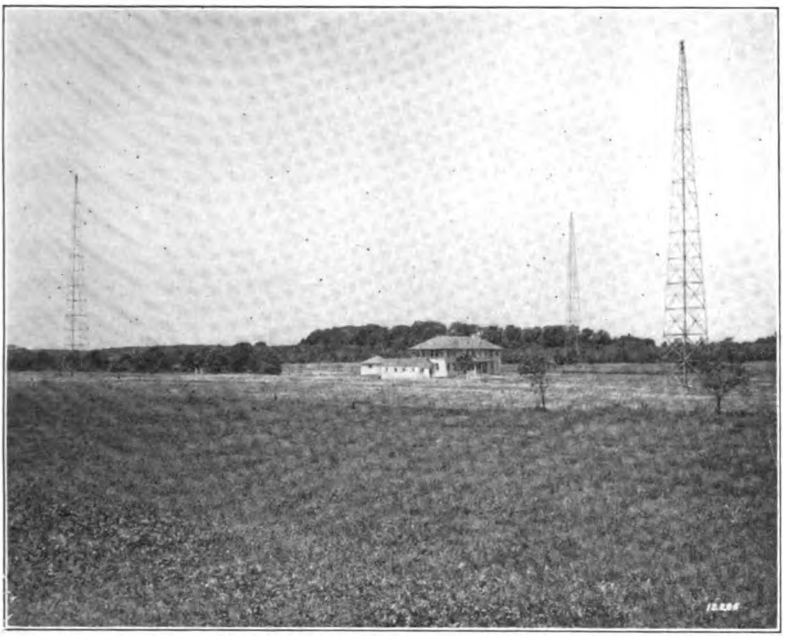

FIGURE 2

Figure 3 is a view of the operating room showing the four transmitting units at the back; the power switchboard for supplying the plate circuits of the tube at the right; the telephone switchboard for the four speech or telegraph channels in the center; and on the gallery above the transmitting units, the coupling coils, loading inductances, and so on, between the sets and the antennas. The motor generator sets capable of supplying as much as five kilowatts at eighteen hundred volts to each of the transmitting sets are located in an adjoining room and controlled from the operating room.

Figure 4 shows the interior of one of the transmitting units. In the shielded box at the upper right hand corner is the master oscillator which sets the frequency to be used for that particular

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channel. Next to the left are two more shielded compartments, each of which contains an amplifier. The last one comprises fifty watt tubes. In the larger unshielded compartment are located, above, the six radio frequency power amplifiers. The reason for introducing two amplifiers between the master oscilla-

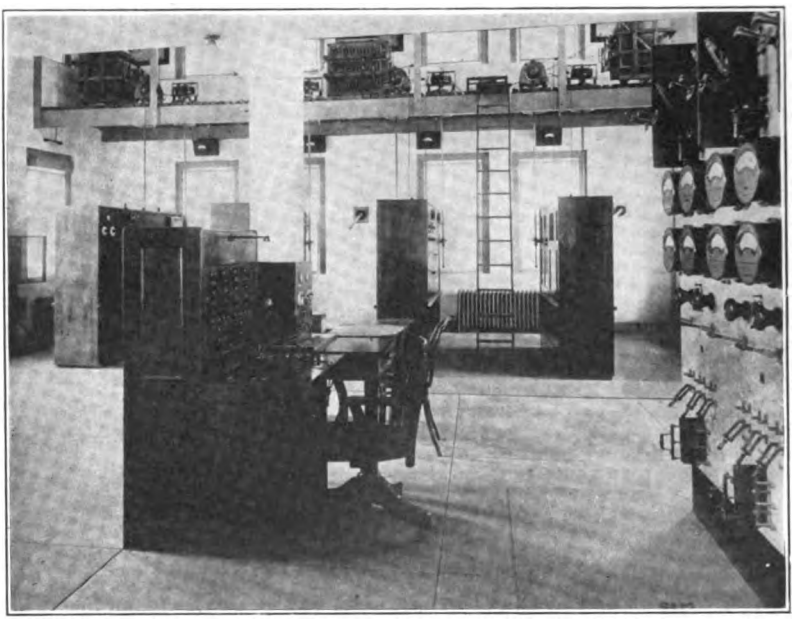

FIGURE 3

tor and the power tubes is to prevent any reaction from the antenna circuit back to the master oscillator. By taking this precaution the frequency of the master oscillator never varies more than fifty cycles in eight hundred thousand. The lower set of shielded compartments, at the right, contains the audio frequency telephone amplifiers which supply currents to the six modulator power tubes shown in the lower part of the open compartment. These two sets of six tubes each are connected together to secure constant current modulation. The output of these twelve tubes is led to terminals on the output of the transmitter unit at the left. To secure cooling in hot weather, a fan is installed below the power tube compartment. In the extreme left compartment are shown choke coils in the power circuits, and at the extreme left on the outside are circuit breakers and two handles for operating the tuning and coupling apparatus in the gallery above.

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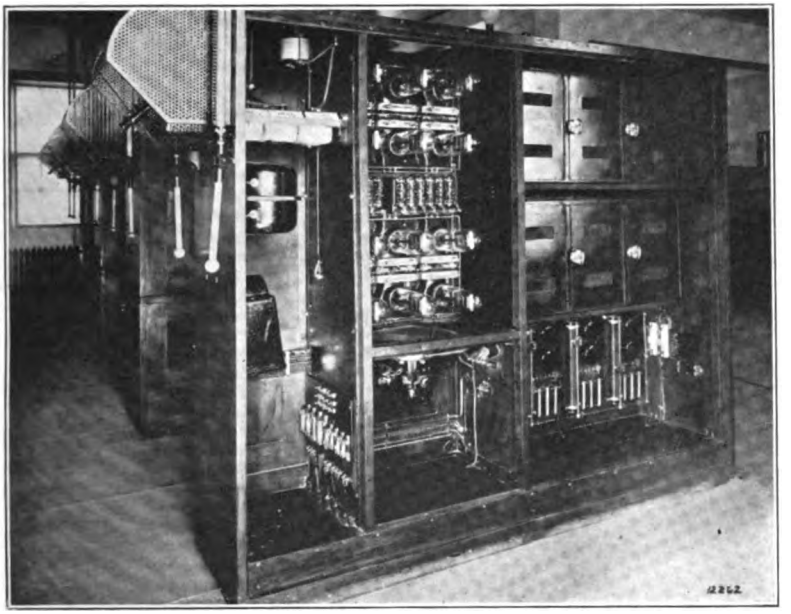

FIGURE 4

Figure 5 shows one set of radio frequency apparatus in this gallery. The two inductometers at the left are for coupling and tuning, and the large condenser at the right, the plates of which consist of brass frames covered with copper window screen, is inserted in series with the antenna. This capacity together with the inductance immediately above it, stiffens the antenna circuit and increases the frequency selectivity to prevent radio frequency interaction between the several antennas.

The telephone switchboard shown in Figure 6 is a special type of P. B. X. (private branch exchange), constructed to provide the necessary shielding and to include telegraph oscillator, phantom coils, and other special apparatus. This switchboard provides for four channel telephone or telegraph operation and for the control and monitoring of all channels. In the operation of the system one operator, located at this switchboard, has complete control of the entire transmitting plant. The operating board was especially built for the experiments, and altho not the final form contains features which are of interest in that they illustrate well the technique involved in combined wire and radio operation.

The four vertical rows of jacks correspond to the four two-way

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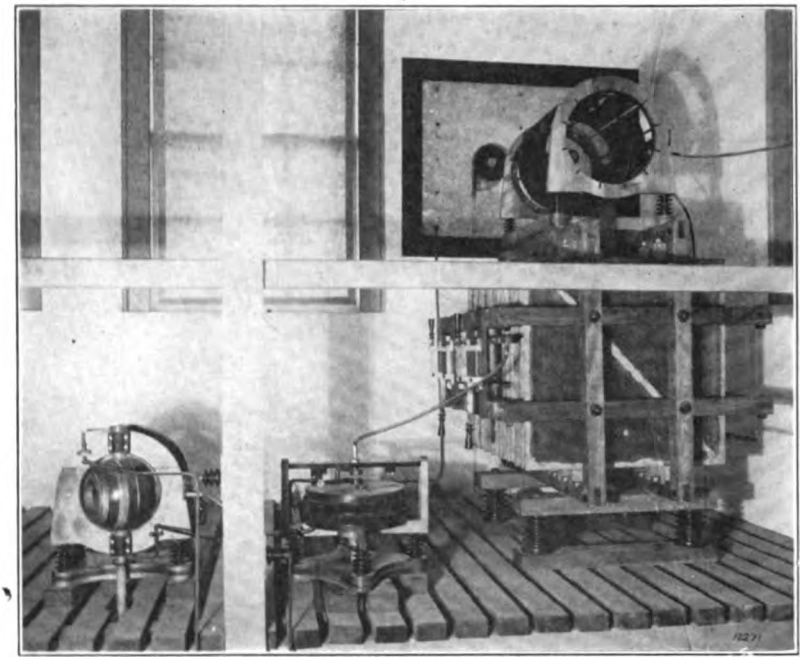

FIGURE 5

radio channels. At the top of each row will be seen the dials for controlling amplification. On the apron are telegraph keys, telephone keys, and operating cords. The cord circuits, by being plugged into the jacks, interconnect any one of the New York toll circuits with any one of the four radio circuits. The cord circuits contain the switching keys seen in front, by means of which the radio station operator is enabled to split the circuit and talk either way, connect the circuit thru and bridge on it and talk or monitor. This cord circuit is shown in Figure 7 in relation to the rest of the wire-radio junction circuit. It will be seen to be of a four-wire instead of the more usual two-wire type and to comprise in reality two circuits, one for east-bound and the other for west-bound transmission. This arrangement was used in order to obtain flexibility in the experiments. It enables the circuits to be continued inland as four-wire circuits and permits of the switching operations being carried out with a minimum effect upon the 2-way balance of the transmission system.

The receiving station at Elberon is located on a rented plot of ground and was not built in permanent form, since we did not regard this location as entirely suitable for receiving from the

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Atlantic. Reception is carried on the four channels by means of four loop antennas operating into four receiving sets. A telephone switchboard similar to that at Deal Beach provides for the connection to the wire system. Of course, two telephone switchboards are not necessary but one was installed at each station in order that we might determine by operating tests whether the control of the system should be from the transmitting or the receiving station.

The receiving sets as finally developed were extremely selective and pass only a band of speech width with a large attenuation outside this band. They will be described in another paper.

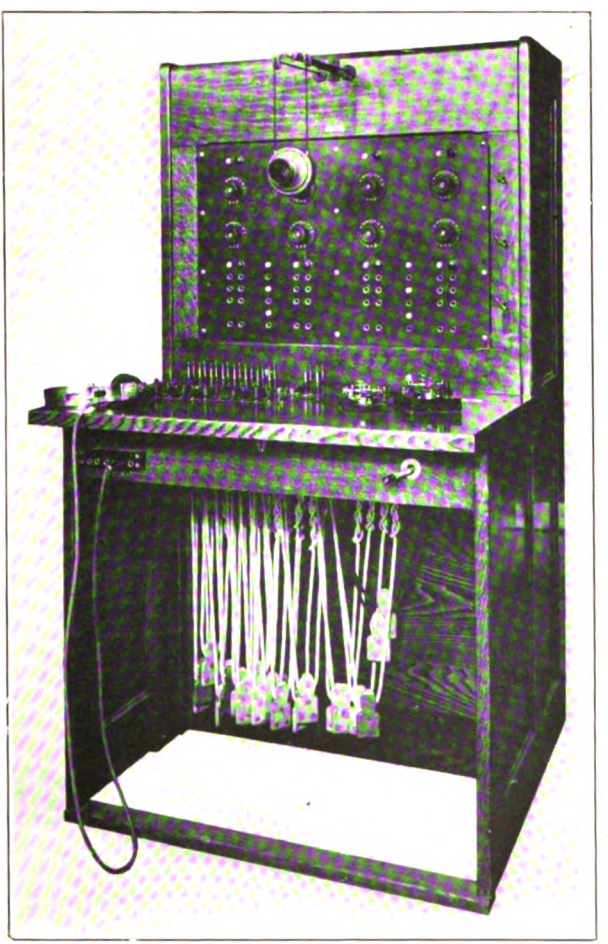

FIGURE 6

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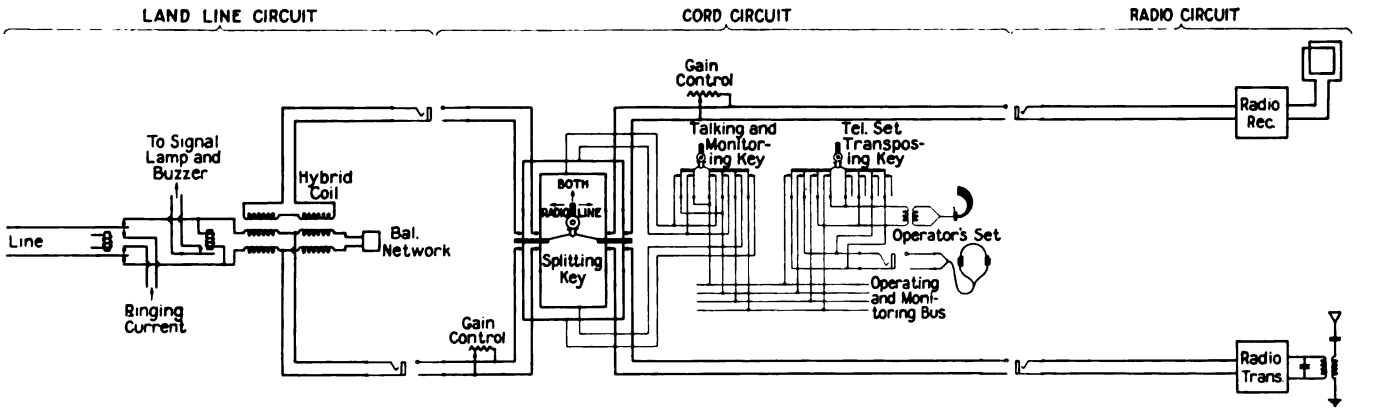

FIGURE 7—Land Radio Station Operating Circuits

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Figure 8 shows a front view of one of the experimental transmitters used aboard ship. The lower half consists of power control apparatus. Three 250 watt tubes are used of which one is

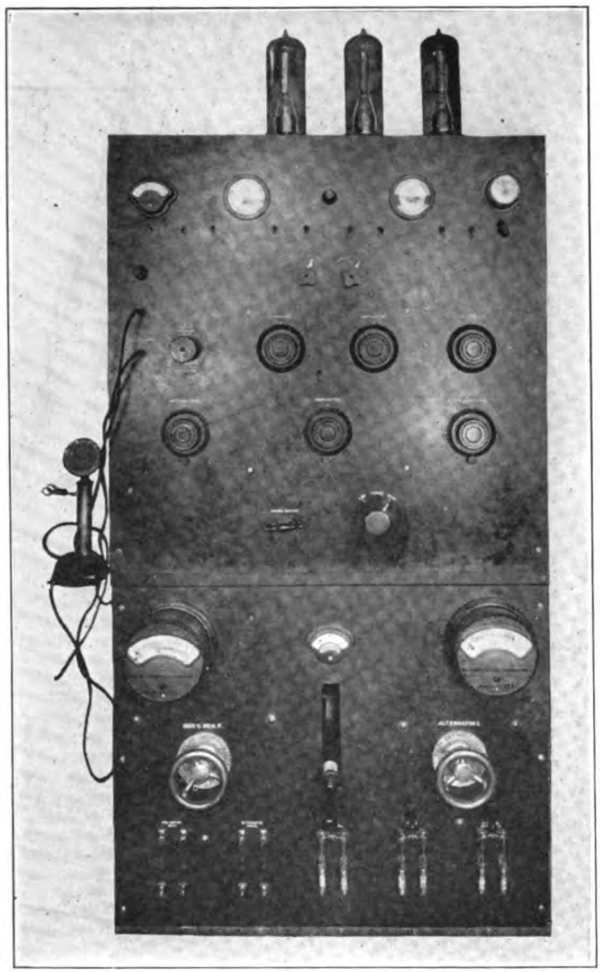

FIGURE 8

a master oscillator, one a power amplifier and one a modulator. The large capacity tube was used as a master oscillator and only a very small part of its output applied to the second power tube. This was done in order to prevent reaction of the antenna system upon the oscillator.

Apparatus of this type was installed on the "Ontario" and "Gloucester" of the Merchants and Miners Line, and operated

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in conjunction with Deal Beach and Green Harbor. Later another electrically similar set was built by the General Electric Company and was installed and operated by the Radio Corporation on the steamship "America." This installation is illustrated in Figure 9.

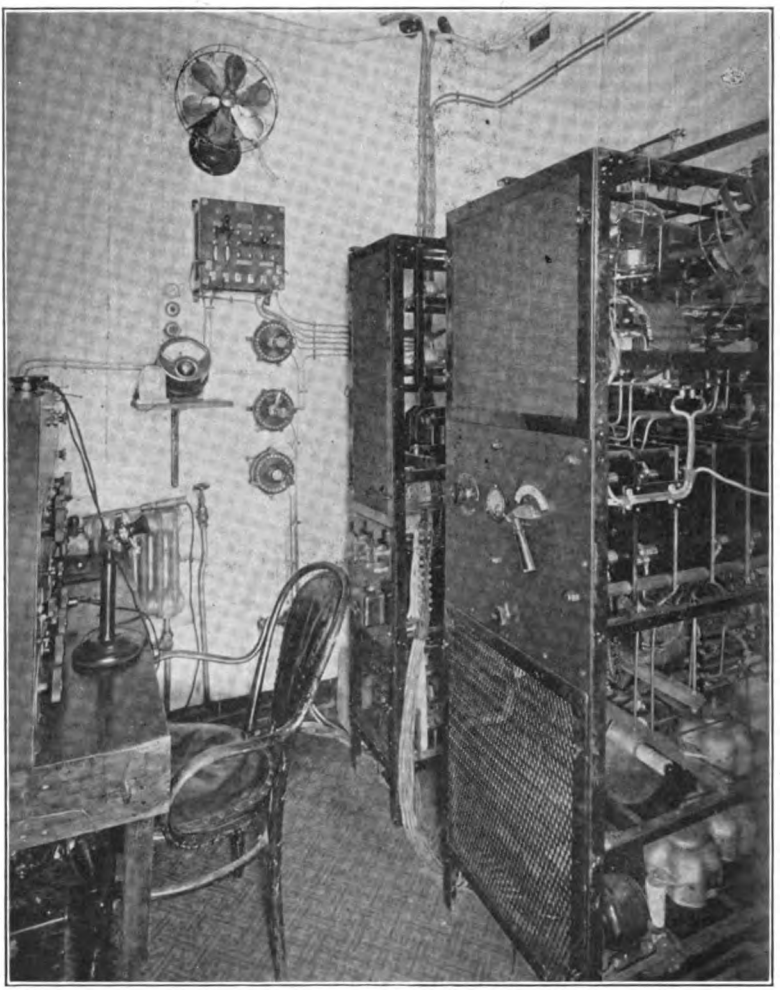

FIGURE 9—Duplex Radio Set Installed by the General Electric Company on the S. S. *America*

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PART II

OPERATION OF THE COMBINED RADIO AND WIRE SYSTEM

The development work as described in Part I had resulted in establishing an experimental ship-to-shore radio telephone plant of some proportions. This will be seen by reference to the accompanying map of Figure 10 which gives a picture of the field setting, as it were, of the experimental operations. The experimental plant included:

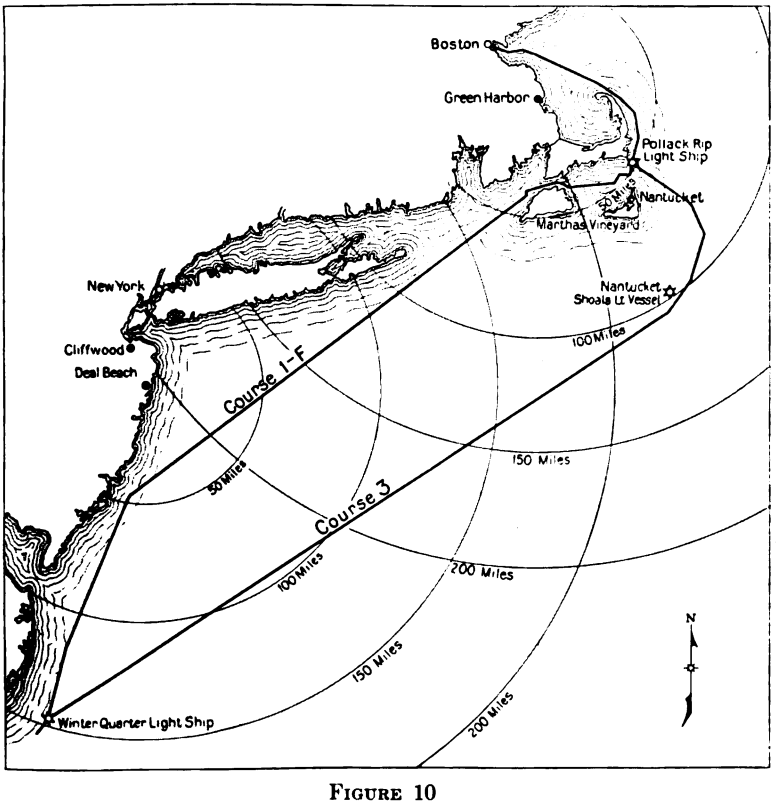

FIGURE 10

Two operating shore stations—Deal Beach, New Jersey, and Green Harbor, Massachusetts.

A field experimental station at Cliffwood, New Jersey.

Two ship installations, on the S. S. "Gloucester" and the S. S. "Ontario."

The vessels operated between Boston and Philadelphia or

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Baltimore and took any of several courses, two representative ones of which are as plotted in the figure.

Let us now consider this plant from the communication standpoint and look into its characteristics, first as an electric transmission system, and then as a message handling facility.

Each of the two land stations was tied into its nearest center by wire circuits, Deal Beach to New York and Green Harbor to Boston. We will take for our example the New York-Deal Beach-Ship circuit pictured in Figure 11 and shown diagrammatically in Figure 12. This is a combination of wire-radio toll circuit,

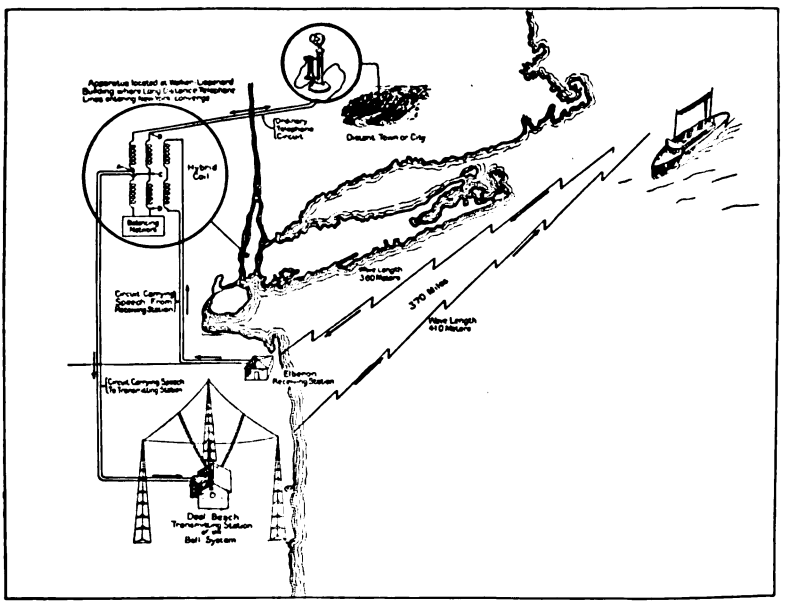

FIGURE 11

one end of which terminates on a vessel of variable position and the other end of which is capable of being extended either over a local circuit to a New York subscriber or over a long distance circuit to reach subscribers at more distant inland points.

This communication circuit must fulfill two general requirements. In the first place it must be so constituted electrically as to preserve the feeble voice currents launched upon it by one subscriber so that they be rendered to another person with sufficient volume and fidelity of wave shape to be readily intelligible. This requires that the circuit be properly engineered as an electrical transmission network. Secondly, given a circuit

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capable of talking, it is necessary that this circuit be flexible in use so that it can be put at the disposal of any land line subscriber for connection to a ship at sea, at any time the ship is within range. This requires that the proper switching facilities be provided and brings in operating and traffic problems.

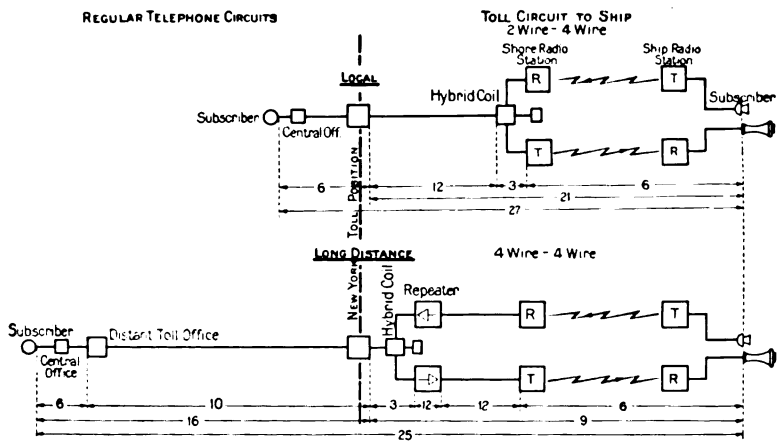

Figure 12—Combined Wire and Radio Circuits

The Radio-Wire Transmission Circuit

Two types of circuits were used in the experiments in operating between New York and the vessel, as shown schematically in Figure 12. The radio link is the same for both. Different frequencies are used for transmitting in the two directions so that in the radio link we have the equivalent of two circuits, one for transmitting east and the other for transmitting west. This is the same as the four-wire telephone circuit. In the thru circuit first shown, the radio four-wire circuit is brought into a two-wire circuit at the land radio station, making a regular two-wire telephone circuit from the radio station to the New York toll terminal. This circuit was used in the tests for calls local in New York. In the arrangement of the second circuit of Figure 12, each of the one-way radio channels is extended back to the New York toll office by its own wire line and there joined into a two-wire circuit, making the wire-radio toll line from New York to the ship a four-wire system. This arrangement forms a high grade circuit and is the one used in the experiments for connecting with long distance lines.

Taking the four-wire circuit, the path of the voice currents may be traced thru from one end to the other as follows: The

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currents which are initiated by the land subscriber, for example, upon arrival at the New York toll office divide in the hybrid coil between the east-bound and the west-bound circuits. The currents are prevented from being propagated over the west-bound branch because of the unilateral nature of the repeater. The currents of the east branch are amplified in the repeater of this circuit in order to make up for the attenuation suffered in the cable circuit, and upon arrival at Deal Beach are amplified to power proportions, modulated upon the radio carrier and radiated into space. Upon being received at the ship end of the radio circuit they are sharply selected in respect to frequency, are again amplified, and delivered to the listener. When the ship subscriber talks, the voice currents are amplified, pass directly into the radio transmitter, are transmitted over the radio link in the usual way, received at the shore station, amplified and sent out over the wire circuit to New York. Here they pass in the reverse direction thru the hybrid coil and divided between the two-wire circuit on the one hand and the balancing network on the other, thus getting back into a regular two-wire telephone circuit.

Interconnection Between Radio and Wire Circuits

It will be well to recall at this point just what it is that makes possible automatic repetition or thru transmission between the wire and radio circuits.

There is both an outgoing and an incoming radio channel. The automatic repet tion from the wire to the outgoing radio channel is made possible thru ability to control the transmitter wave power by the voice currents set up at the distant end of the telephone line. It will be recalled that in the early radio telephone art, before the vacuum tube, modulation was effected by the microphone transmitter which required that the talker be present at the radio station. It is, therefore, the electric-control type of modulator such as the vacuum tube, as distinguished from the air-wave control modulator, which permits of the talker being at the far end of a wire circuit. Conversely in the receiving channel, it is the fact that the detecting action yields telephone currents directly, ready for propagation over a wire circuit, that enables the radio channel to be extended to a distant listener.

Thus it is the thermionic tube modulator and detector which have made possible the radio-wire transfer. It is the thermionic tube as a reliable high-quality amplifier, however, that makes the transfer practical; for it is the amplifier which enables the weak voice currents received at the radio station from a land

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line subscriber to be boosted to power proportions and thus control the considerable radio frequency power required for transmission; and, again, it is the amplifier which enables the extremely weak currents received from the radio link to be so augmented that upon being placed upon a wire circuit, and perhaps being further amplified en route, they may be heard in the regular telephone at the other end.

The other important feature of the radio-wire inter-connection is the junction of the four-wire and the two-wire circuits by means of the hybrid coil and balancing network as shown in Figure 11. The windings of such a coil are so designed as to establish a sort of Wheatstone bridge circuit. This bridge circuit accomplishes the joining of the regular two-wire telephone circuit with the sending radio channel on the one hand and the receiving radio channel on the other, while still maintaining an electrical separation between the two radio channels. It is really, therefore, the connecting link between the two-wire type of circuit of the telephone plant and the four-wire circuit of the radio link. The hybrid coil type of circuit, is taken from the telephone repeater and carrier current art.[1] The radio receiving circuit corresponds to the generator branch of the Wheatstone bridge, and radio transmitting circuit to the detector branch. The two-wire telephone line corresponds to the "X" arm of the bridge and the balancing artificial line to the "Y" arm. The ratio arms are in effect formed by the windings of the hybrid coil.

Speech Received from Ship Re-Transmitted from Shore Station

Now this junction circuit always has some unbalance because it is obviously impossible to maintain a perfect symmetry between the telephone line and the balancing network. Especially is this true where the telephone line is a type not designed for repeater operation and is switched at its terminal to any of a number of lines of different impedances, as was the case with the circuit used in the tests.

This unbalance between the line and its balancing network will be seen to permit some of the speech-current received over the radio link to get across into the transmitting circuit, to modulate the shore station carrier and to get out into the ether

[1] "Telephonic Repeaters," B. Gherardi and F. B. Jewett, "Journal of American Institute of Electrical Engineers," pages 1255-1395, November, 1919.
"Carrier Current Telephony and Telegraphy," E. H. Colpitts and O. B. Blackwell, "Journal of American Institute of Electrical Engineers," pages 205-300, February, 1921.

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again on the transmitting wave length. As a matter of fact during the experiments the unbalance was sometimes such as to permit of fairly strong transmission around back thru the shore transmitter, so that incoming speech was repeated out thru tne shore station transmitter in amplified form. This enabled listeners in the vicinity of New York to hear the conversation originating on the ship almost as well as that originating on land, and they naturally thought that they were picking up the ship's radio transmission directly, whereas they were actually overhearing the re-transmission of the shore-station's reception.

The Thru Circuit as a Repeatered Telephone Circuit

This re-transmission makes all the more evident the true role of the shore station, namely, that of a large telephone repeater, repeating between two sections of line, the one a land line and the other a "space" line, and functioning also to convert between the voice frequencies of one section and the radio frequencies of the other. As such, we can consider the over-all circuit from a transmission standpoint much as we do long distance repeatered telephone circuits.

Now one of the most important transmission considerations in such a long distance circuit is that of how the amplification is applied in relation to the losses in the circuit. This question of amplification is particularly important in the case of combination radio-wire systems, because the radio circuit possesses inherently large transmission losses and requires correspondingly large amplification. The necessary large amplification is supplied at both ends of the radio link, partly in the transmitting station where the voice currents are amplified up to power proportions and partly at the receiving end where the amplification is likewise large altho at small power. In the radio telephone circuits which were operated in the experimental work the power in the sending antenna to that in the receiving antenna is in the ratio of roughly 10^{10}. This required amplification which was distributed somewhere near equally between the sending and the receiving ends. It has been found convenient to express such transmission losses in terms of a power ratio using $10^{0.1}$ as a unit.[2]. Thus the above antenna-to-antenna power ratio would correspond to 100 of such units.

[2]The unit used in this paper is one which has been found convenient in expressing the transmission loss or gain of a circuit. One unit is taken as that power ratio which is equal to $10^{0.1}$. Thus, if the attenuation or amplification of a circuit is one unit the power at the two ends are in ratio of $10^{0.1}$; if ten units, in the ratio of $10^{(10\times0.1)}$ or 10; twenty units would therefore have a power ratio of 100, and so on. The advantage of using a power ratio instead

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It is necessary that the amplification of such a circuit be sufficient to offset very closely the loss, in order that the net loss be small. Actually, in the tests, the radio portion of the circuit was worked with a net transmission loss of about six units meaning that at least 95 percent of the radio over-all circuit losses were wiped out. This means that if a change of say 10 percent occurs in the amplification, or in the ether loss as by fading or movement of the vessel, the circuit equivalent will be greatly affected—changed by about 200 percent. The difficulty of maintaining the ship circuit stable will therefore be appreciated.

Figure 12 shows the transmission loss (of six units) obtained for the radio link during the tests and also the other losses which are in the wire portion of the combination system. The distribution of losses in the first circuit will be noted to be approximately as follows:

6 units in the radio link.
3 units in the hybrid coil—balancing network.
12 units in the wire circuit to New York.
6 units from the New York central office to the subscriber.

This makes a total loss between subscribers of 27 units which is satisfactory for a good talk under fairly quiet conditions. This equivalent was usually realizable under the conditions of the test and the majority of the calls put thru from local stations in New York with the ship 100-200 miles (160-320 km.) out were successful despite occasional spark interference in the radio circuit.

The transmission loss is, however, too high in such a circuit to enable it to be extended inland over long distance wire circuits. If this is attempted, two limitations come into play. In the first place, the volume of the talk becomes too weak. If the call were extended over a toll circuit having a 10-unit equivalent, for example, the over-all equivalent would become something like 37 unit, which is excessive. This could be overcome to some extent by a cord circuit repeater at New York. A second limita-

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of a current ratio is that it is independent of the impedances of the two portions of the circuit considered. The advantage of expressing the power ratio as an exponent is that on account of the exponential nature of attenuation it enables the net transmission efficiency of a system to be readily derived by algebraically summing up the individual losses and gains. This unit has been selected as more suitable for general use in expressing transmission efficiencies than the 800 cycle "mile of standard cable" which has sometimes been used. The ratio between these two units is as follows: 1 mile of standard cable equals 0.95 units as used in this paper. $\frac{P_1}{P_2} = 10^{0.1} = \frac{1}{0.95}\epsilon^{2(0.109)}$ units.

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...perimental set-up resided in the un-
... and the balancing network at the radio
... permitted currents received over the
... thru the radio transmitter of the land
... above. These fed-back currents overload
... if they are large compared with the currents
... to the radio transmitter from the shore sub-
... In other words, if there is sufficient amplification in
... transmitter to enable very weak voice currents arriving
... a line of high equivalent to load the transmitter fully, then
the transmitter is likely to be overloaded by currents which get thru the hybrid coil from the associated radio receiver. For these reasons, the two-wire-four-wire circuit of Figure 12 is not good enough for extension over long distance circuits.

The four-wire type of circuit which is suitable for long distance land line connections is shown in the second diagram with representative transmission equivalents. A brief comparison of the two-wire and the four-wire circuits will make it evident why the four-wire circuit gives the better equivalent. It enables the land line loss between the radio station and the toll center to be more or less wiped out, thus in effect placing the radio station electrically at the toll center. Another way to express the situation is this: regard the hybrid coil unbalance as the limiting factor, then assume that, while holding to a given unbalance, the four-wire circuit (the loss in which can be largely wiped out by one-way amplifiers) is extended inland. The length of the remaining two-wire line back to the land subscriber is thereby decreased and the ratio of the current received at the radio station over the line as compared with that transmitted across the hybrid coil thru unbalance is increased. It will be observed that with the circuit conditions as illustrated, the overall equivalent between, say, a Chicago subscriber and a ship, including a 10-unit toll circuit loss, is approximately 25 units, which should give a good talk.

Power Levels and Interference

It is necessary that the magnitude of stray currents be so kept down in comparison to the transmission currents thruout the system as to obviate noise interference with telephone conversation. This requirement is particularly difficult of realization in the radio link because of static and, especially in the vicinity of New York, interference from spark telegraph stations. It is, of course, this interference, caused by the presence in the ether,

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on the wave length band being used, of extraneous wave components, which sets the actual range limit of the radio link. Actually it was found that in transmitting on about 400 meters in the vicinity of New York the receiving field strength could not be permitted to go on the average below about 200 microvolts per meter, and even then the spark situation is so bad in the present art as to give periods of prohibitive interference. In less congested zones along the coast to the north, probably lower field strengths could be permitted.

Transmission Variations in Radio Circuit

One of the outstanding transmission characteristics of a ship-to-shore radio telephone system is the variation which the attenuation of the radio link undergoes as a result of the movement of the vessel. In order to determine the magnitude of these variations, a series of measurements were made of the telephone transmission over the radio circuit as the vessel proceeded on her course.

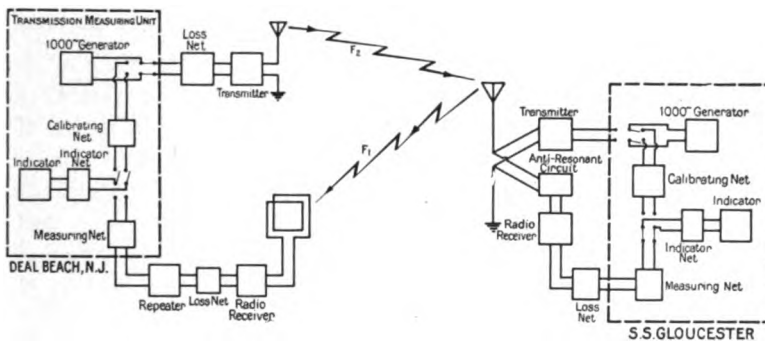

Figure 13—Measurements of Telephone Transmission of Radio Circuits

The method of making these measurements is shown schematically in Figure 13. Take for example the case of measuring a one-way circuit as distinguished from a circuit looped back. A 1,000-cycle current of predetermined power of the order of one milliwatt is impressed upon the input circuit of the radio transmitter. This tone is received in the output of the distant radio receiver. There it is passed to the measuring apparatus where it is amplified, rectified, and made to operate an indicating instrument. The receiving end measuring apparatus is then switched to a local source of 1,000-cycle current giving the same power as was applied to the transmitter at the sending end. The proportion of this power which enters the measuring apparatus

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is then varied by a variable network calibrated in power ratio loss (it was actually in miles of standard cable), until the indicator reading is the same as that obtained from the radio receiver. The setting of the variable network then indicates the transmission loss of the circuit. The method is similar to that developed for measuring the transmission loss of telephone circuits.

These measurements were used for the purpose of enabling the radio link to be worked to a constant transmission equivalent —in this case, of about six units. The procedure for so doing was as follows: When the vessel was first picked up, the receiving amplifications in both east and west channels were adjusted until the measurements showed a transmission equivalent of 6 units. Then as the vessel proceeded on her course the transmission equivalent was measured at intervals of an hour or less and the receiving amplification readjusted to hold the desired six-unit equivalent. In this way, the talking efficiency of the radio link, was kept constant.

The total amplification change which had been made from the beginning of a run up to any one time gives a measure of the change which has occurred in the transmission loss of the radio circuit. By plotting this change in relation to the time of day and in turn to the varying distance between the two stations, an interesting curve results which shows the manner in which the progress of the vessel affects the transmission of the radio circuit. In Figure 14, the time of day is plotted horizontally, distance is plotted vertically on the right and amplification vertically on the left. The zero amplification reference is the amplification in the circuit which gives a six-unit equivalent at the time the vessel is first picked up.

Curve A shows the manner in which the distance between shore-station and ship varied with time of day as on her southbound course the ship approached the shore station from the northeast and drew away again to the south. The vessel in this case was on her inshore course along the coast as shown in Figure 10 above. Curve B shows the manner in which the receiving amplification on shore had to be changed with time of day to keep the ship-to-shore transmission constant, first decreased as the ship came closer and then increased as she drew away again to the south. Curve C is for reception on ship and shows the manner in which the ships receiving amplification had to be varied to keep the shore-to-ship transmission constant. Altho these are not measurements of any absolute quantity such as field-strength, they are practical measurements af actual talking circuits and

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as such include the effect thereon of apparatus adjustments as well as the "ether" conditions and therefore are of value in determining the conditions to be met in maintaining the over-all system in operation. The difference between curves B and C,

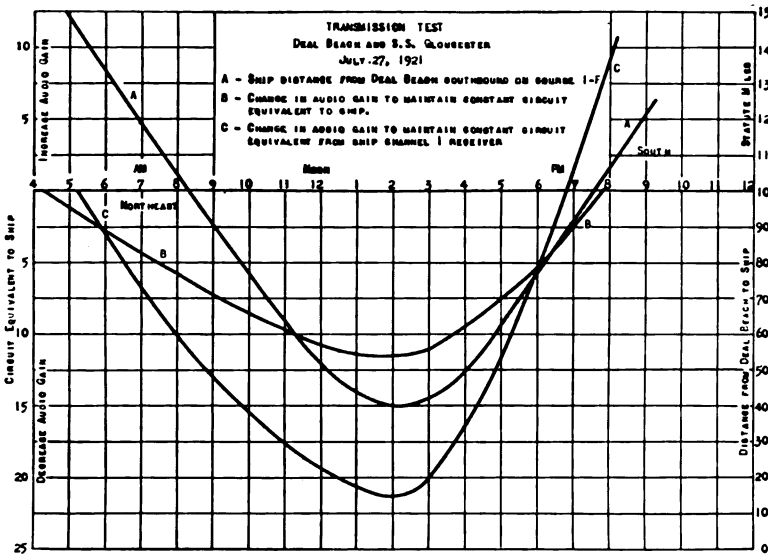
TRANSMISSION TEST
DEAL BEACH AND S.S. GLOUCESTER
JULY 27, 1921
A - SHIP DISTANCE FROM DEAL BEACH SOUTHBOUND ON COURSE I-F
B - CHANGE IN AUDIO GAIN TO MAINTAIN CONSTANT CIRCUIT EQUIVALENT TO SHIP.
C - CHANGE IN AUDIO GAIN TO MAINTAIN CONSTANT CIRCUIT EQUIVALENT FROM SHIP CHANNEL I RECEIVER
INCREASE AUDIO GAIN
DECREASE AUDIO GAIN
CIRCUIT EQUIVALENT TO SHIP
DISTANCE FROM DEAL BEACH TO SHIP
STATUTE MILES
NORTHEAST
SOUTH
AM
NOON
PM

FIGURE 14

for example, are in part the result of the difference in adjustment given to the detector tubes of the two circuits. The load on the detectors was kept practically constant by adjustable radio-frequency amplification so that any overloading was approximately constant thruout the measurements and had the effect of minimizing the variation of circuit equivalents with distance.

The curves of Figures 15 and 16 are obtained by taking the data of Figure 14 and plotting the variation of amplification with separation between stations. The minimum point is arbitrarily chosen. These curves show up rather strikingly the fact that the transmission to the south is much poorer than that to the northeast of Deal Beach. This result agrees with experience since greater difficulty is usually encountered in communicating with a vessel when the line of transmission is along the coast than when it is straight out to sea. The larger transmission loss may be due to shore absorption or, possibly, to refraction of waves by the electrical discontinuity represented by the coast line. This high attenuation effect was observed rather uniformly in all of the measurements, and would itself form an interest-

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ing subject of investigation, using more absolute methods of measurement.

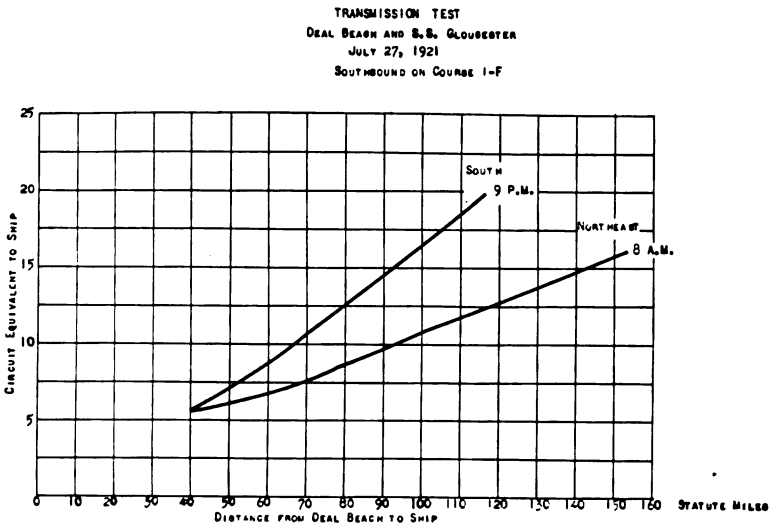

FIGURE 15

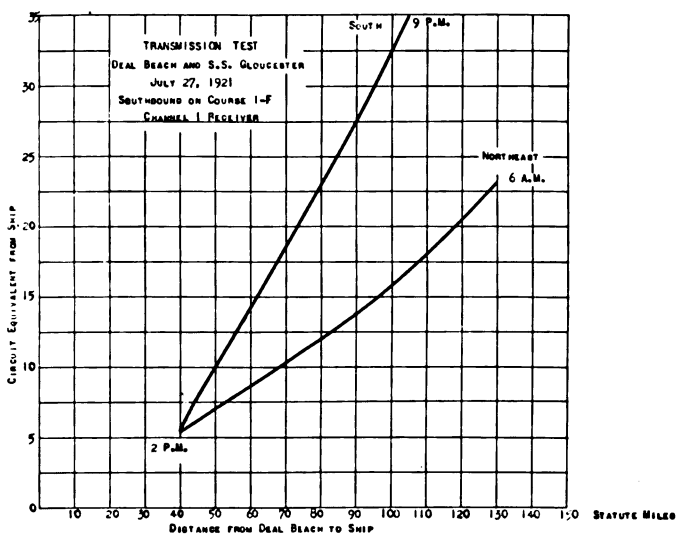

FIGURE 16

Figure 17 shows the circuit-equivalent-distance characteristic for the off-shore course taken by the vessel. The curve is generally similar to that for the near-in course.

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The rate at which the transmission of the circuit varies with change in distance is an important matter in operation, since it determines the frequency with which the amplification in the circuit must be readjusted to keep the equivalent constant. In accordance with the Austin-Cohen formula, the equivalent

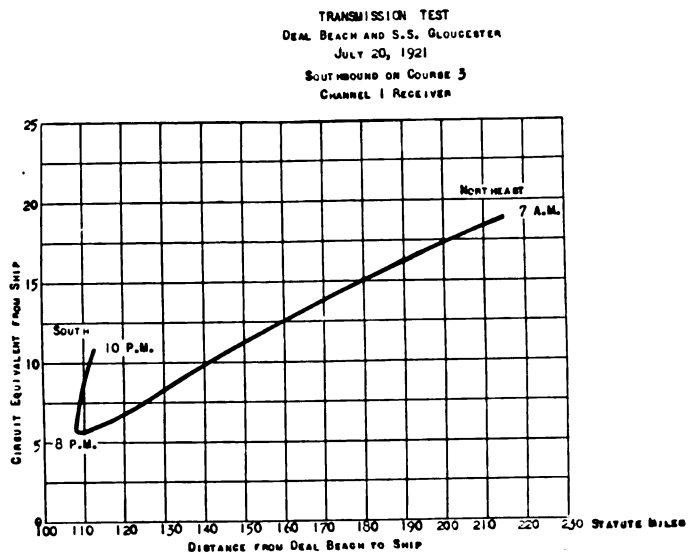

FIGURE 17

should vary at the rate of about 0.25 units per statute mile (1.6 km.) with the vessel 100 miles (160 km.) out, assuming a square law detector. In the worst case found, the circuit equivalent varied at the rate of 0.5 unit per statute mile. This was one of the cases where the vessel was well south and close in shore and, of course, represents very poor transmission. It means that with the vessel traveling as slowly as ten miles (16 km.) per hour, a transmission change of about five units per hour will occur. In telephone practice it is desirable to keep the transmission equivalent constant to within two or three units, so that this condition would require re-adjusting the amplification as often as every half hour.

These curves show the necessity for so designing the receiving set as to be able readily to obtain a wide variation in amplification in order to accommodate the changes in transmission efficiency. Under the conditions of the test, it was found that a variation of 40 units amplification is necessary in order to carry

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the vessel from a range of 40 up to 200 statute miles (64 to 320 km.). In order to gain such control, it is desirable to switch stages of amplification into and out of the circuits and to obtain closer adjustment by means of networks of variable loss.

When we speak of holding the circuit to a constant transmission equivalent thruout a wide variation in the position of the ship, we do not mean that the circuit for 200 miles (320 km.), for example, is as good as that for 40 miles (64 km.). The field strength received over the longer circuit is, of course, very much weaker than that received over the shorter one, and is subject to correspondingly more interference. For a transmitting power of about one kilowatt used in the tests, it was found that the circuit was rather consistently good up to 100 miles (160 km.) or so. During summer daylight condition, it was only fairly good at around 150 miles (240 km.), and at 200 miles 320 km.) was subject to so much interference that its insurance against interruption in service was small. Under more favorable conditions, particularly as at night in the winter time, connections could be established over very much greater distances, but not reliably.

Field Strength Measurements

The circuit transmission measurements described above were supplemented during the latter end of the experiments by measurements of a more fundamental nature, namely, of the received field strength. These measurements represent the application to the ship-to-shore development program of what was really another investigation—that of the development of methods and apparatus for measuring field strengths at these relatively short wave lengths as well as for longer wave lengths. The method and means employed will not be described, since they will be the subject of another paper to be given before The Institute of Radio Engineers shortly by the engineers immediately responsible for this development. Field strength measurements will be discussed, therefore, only insofar as the results obtained apply to the ship-to-shore type of system.

The first measurements which were made are given in Figure 18. Time did not permit of checking the results, but they are approximately correct. They show the variation in the strength of field received from the S.S. "Gloucester" during the same trip as the circuit measurements of Figure 14 were taken. The fact that the transmission is considerably better to the northeast from Deal Beach than when the vessel is south is rather strikingly in evidence. The dash-line curve is for the Austin-Cohen formula

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and shows that the field strength versus distance relation checks that formula for these relatively short wave lengths when the path of transmission is practically entirely over sea. The absorption

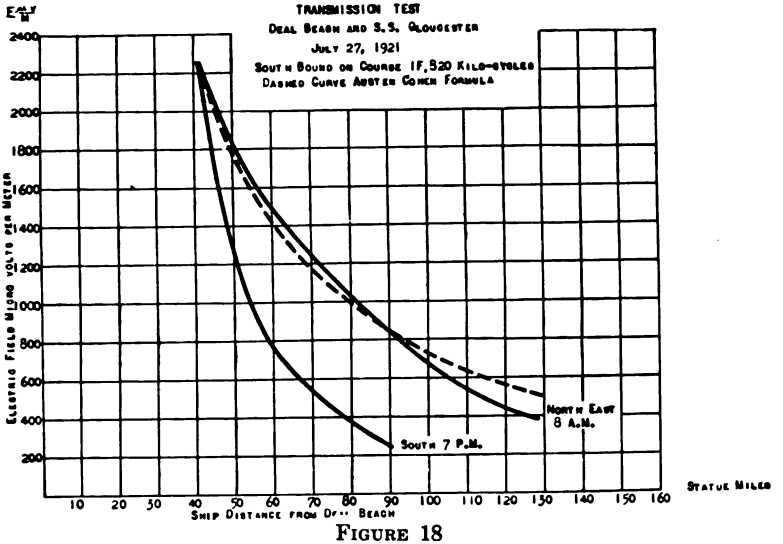

FIGURE 18

coefficient is obviously greater when the path of transmission has a relatively large component skirting along the coast line. The curve shows also that the vessel was picked up and the circuit "made" on this day at a field strength of about 400 micro-volts per meter, then increased as the vessel came nearer and passed the land station to a value of 2,200, and that the circuit was "broken" at about 200 micro-volts. The results of another measurement made on the off-shore course of the vessel are given in Figure 19. A larger proportion of this curve is for straight-out-to-sea transmission where the attenuation law is seen to be normal.

In the field strength measurements made during the ship-to-shore development, those of the S.S "America" en route across the Atlantic are especially illuminating. The results are given in Figure 20. The vessel was in-bound so that the curve develops from the right to the left, altho the effect is just the same as if it developed in the reverse direction with the vessel out-bound as was shown by another set of measurements which gave generally similar results. The actual measurement results are indicated by the points and by the connecting heavy line curve. The light curve A is a plot of the Austin-Cohen formula,

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the absorption term of which is for daylight transmission over water. The light curve B is a plot of the simple inverse-with-distance law without any absorption term.

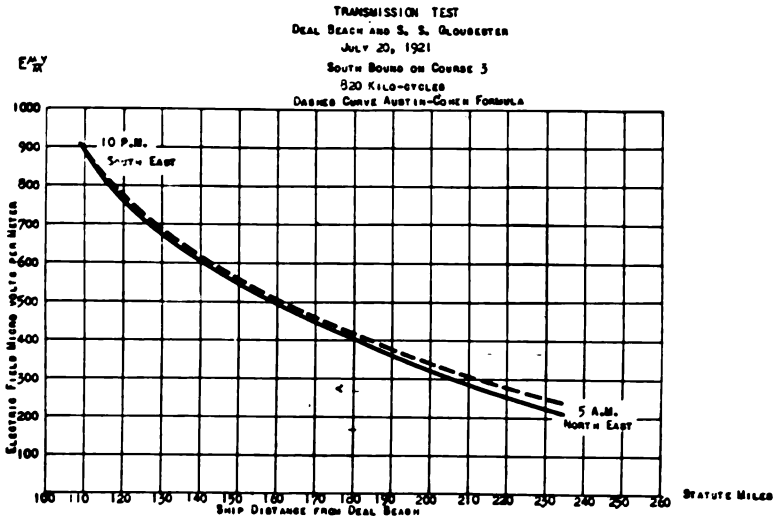

FIGURE 19

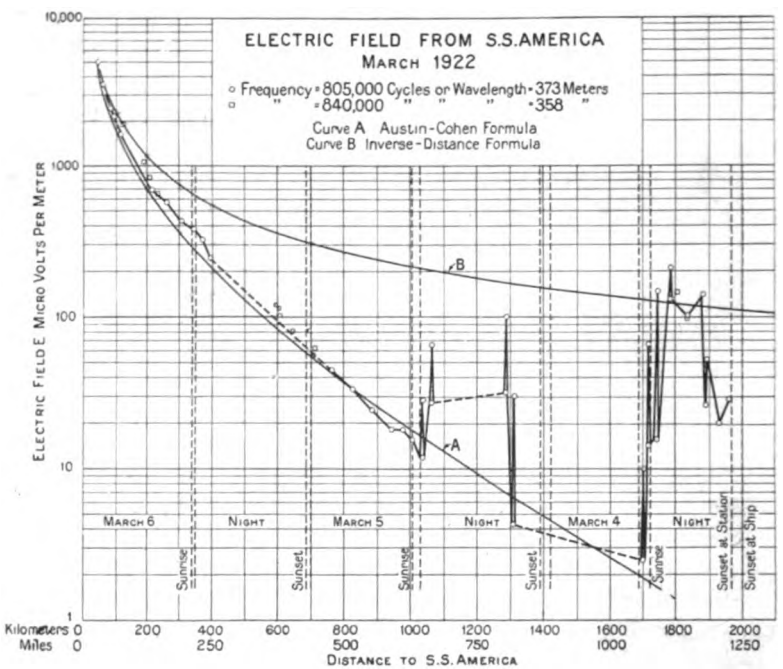

FIGURE 20

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This curve shows up the following important factors:

(1) The enormous variation between day and night in the received field strength which occurs at distances of the order of 1,000 miles (1,600 km.) using wave lengths of 350 to 400 meters as now employed in broadcast transmission. The curve shows night to day variations of the order of 100:1 or a power ratio of 10,000:1. This means, for example, that it would require 10,000 times more power to "get thru" as well during the day as during the best times at night. These enormous day to night fluctuations are now familiar to broadcast listeners. This curve shows the impossibility of giving continuous ship-to-shore telephone service at these relatively short wave lengths for distances as great as 1,000 miles (1,600 km.). For such distances much longer wave lengths will be required, as well as more sending power.

(2) The wide fluctuations which occur thruout the night period. Altho smaller than the day to night fluctuations, their effect upon transmission is still very large. The fluctuations during the third night out, for example, are as much as 10:1 in field strength or 100:1 in power, or about 20 of the power ratio units we have used above. In view of the rapidity with which these fluctuations occur—within a very few minutes—it is practically impossible to maintain a circuit under these conditions satisfactory for regular telephone service.

(3) The most interesting thing to observe is that the fluctuations tend to fall within the two curves A and B. The day transmission is a pretty definite proposition, following closely the Austin-Cohen formula. The night transmission appears in the nature of a "bob-up" from the day condition but seems to be limited in the extent of its "comeback" by the loss imposed by the simple inverse-with-distance law. The fact that the difference between curves A and B is entirely one of absorption suggests that the very large and rapid night fluctuations, which are now so well known to broadcast listeners, may be explained in large part if not in whole, by variations in atmospheric absorption.

Occasional Long Distance Transmissions

Many of the long distance records which have been made on short waves and low power can be accounted for simply on this basis—that the absorption which ordinarily obtains during daylight has been temporarily wiped out. The way in which it is pos-

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sible for the range to "open up" tremendously under exceptionally favorable conditions will be seen from this: Referring to Figure 20, assume that the normal daylight range between S.S. "America" and New York was 250 miles (400 km.) as fixed by a limit taken as 200 micro-volts per meter. Then, at night, this same field strength may be delivered over a distance of about 700 miles (1,100 km.) if the absorption is wiped out in accordance with curve B.

Furthermore, so favorable is the simple spreading-out law at such distances, that the field strength is only halved in going another 700 miles to 1,400 miles (2,200 km.) and only halved again in doubling this distance to 2,800 miles (4,500 km), and so on. In other words under no-absorption conditions, by increasing the receiving radio frequency amplification by a current ratio of only $\frac{1}{2} \times \frac{1}{2} = \frac{1}{4}$, or about 12 power ratio units, the range of transmission may be increased from the reliable daylight range of 250 miles (400 km.) to a possible night range of ten times this distance. It is therefore seen that many if not all of the long distance transmissions which have been realized for short periods of time probably can be explained simply on the basis of there having occurred an exceptional clearing up of absorption at a time of unusually favorable interference conditions.

Setting Up and Operating Combined Radio-Wire Circuits

The operating problems presented by the combination wire-radio telephone system are more difficult than these involved in the operation of either a straight telephone toll line on the one hand or the ordinary radio-telegraph circuit on the other. In regular long distance telephone circuits we have a fixed type of system which is maintained continually in good talking condition and the operators turn the terminals over to the use of the subscribers themselves. On the other hand in a radio telegraph circuit operating between land and vessel the circuit is kept entirely in the hands of skilled operators who have access to the apparatus and who handle the traffic directly between themselves. In no case before have we had the requirement of taking a radio link of varying length, building it up as occasion requires with wire circuits and, upon call, putting the combined system at the disposal of people experienced only in the use of the regular telephone. The technical difficulties of the combination system, together with the necessity of coming as close as possible to meeting telephone standards in the quality of talk given, greatly reduce the length of the radio link which can be used for a service

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as compared with those distances which can be spanned for short periods of time under the most favorable conditions. The effect which the requirement of reliability has in reducing the range of transmission will be appreciated from the discussion of field strength measurements.

There are various ways in which the combination circuit can be set up and operated and it will take further experience before the most satisfactory arrangement is determined upon. In order to explain the operation generally, however, we will describe how the circuit was actually set up during the tests. Take the case of a call originating on the vessel; then the procedure is as illustrated in Figure 21, namely:

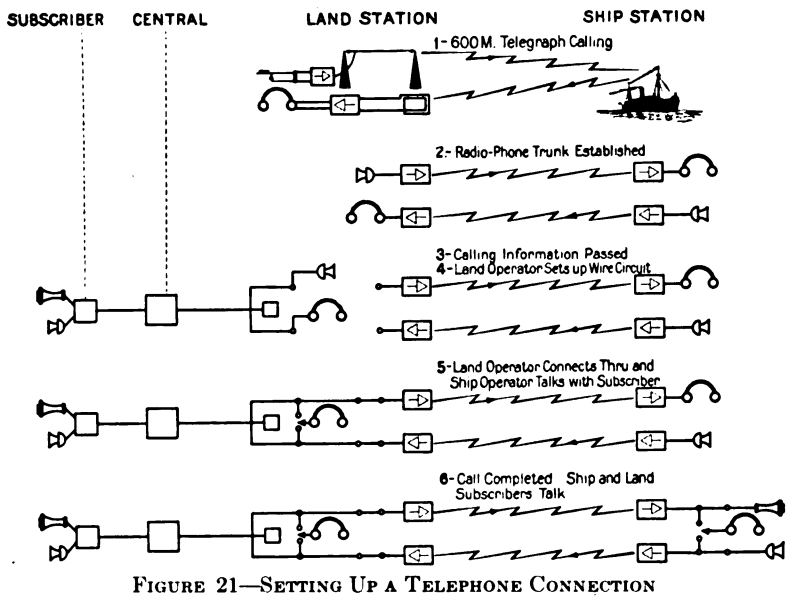

FIGURE 21—SETTING UP A TELEPHONE CONNECTION

1 When the ship comes within range she calls the land station by telegraph on 600 meters, and informs the land station of her message business.

2. The land station then assigns a pair of telephone channels to which both stations switch over and the circuit tested out for talking. In case of important long distance land line connection, this test may involve circuit transmission measurements.

3. The ship operator then passes to the land operator

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by voice (or by tone modulation telegraph) the information as to the connection desired.

4. The land operator then tells the ship operator to stand by while he switches to the wire circuit and passes the call to the telephone central, who in the case of a local call is a local operator (actually, for this case, she was the operator on the New York Cortlandt Official board of the American Telephone and Telegraph Company); or in the case of a long distance call is a toll operator.

5. The land line connection is made in the usual way and the shore station radio operator greets the land line subscribers.

6. The shore station operator then joins together the land line and the radio link thus connecting the land subscriber with the ship operator, who proceeds to tell the subscriber that this is the steamship so and so and that Mr. Blank wishes to talk with him. While this is going on, the land operator is monitoring on the circuit and makes such final adjustments of the amplification as may be necessary.

7. The ship operator then summons the ship subscriber and the latter takes up the conversation.

The handling of calls originated by the land line subscriber presents a more difficult operating problem because of the uncertainty as to the radio link—it not being known whether it can be established and, if so, as to how long a wait will be involved in getting the connection. During the tests, most of the calls originated in the New York area. For these cases the land subscriber was connected to the Deal Beach station and there the call was put thru directly to the ship in case the radio telephone circuit was available. When not available, information as to the call was recorded by the radio operator and the telephone circuit released for the time being. The call was then completed by first setting up the radio link and then calling back the initiating subscriber. It is obvious that the giving of commercial service will involve: first, the ascertaining of whether or not the vessel is within range; second, the "lining up" of the radio link preparatory to the thru connection; and third, the building up of the land line connection back to the calling subscriber and the making of the thru connection. Many detailed variations are possible in the procedure and the determination of the best operating methods will have to await upon experience obtained in actually giving service.

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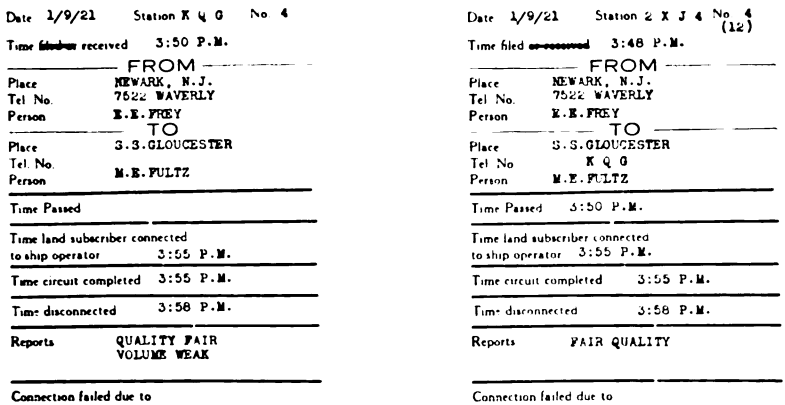
In order to become familiar with the problems involved in maintaining the ship-to-shore system in operation, a series of operating tests were carried out for a period of about three months, starting in January, 1921, and operating between Deal Beach station and the S.S. "Gloucester." In accordance with a



Date 1/9/21 Station K Q G No 4

Time ~~filed~~ received 3:50 P.M.

FROM

Place NEWARK, N.J.
Tel. No. 7522 WAVERLY
Person E.E.FREY

TO

Place S.S.GLOUCESTER
Tel. No.
Person M.E.FULTZ

Time Passed

Time land subscriber connected to ship operator 3:55 P.M.

Time circuit completed 3:55 P.M.

Time disconnected 3:58 P.M.

Reports QUALITY FAIR VOLUME WEAK

Connection failed due to

Date 1/9/21 Station 2 X J 4 No 4 (12)

Time filed ~~as received~~ 3:48 P.M.

FROM

Place NEWARK, N.J.
Tel. No. 7522 WAVERLY
Person E.E.FREY

TO

Place S.S.GLOUCESTER
Tel. No K Q G
Person M.E.FULTZ

Time Passed 3:50 P.M.

Time land subscriber connected to ship operator 3:55 P.M.

Time circuit completed 3:55 P.M.

Time disconnected 3:58 P.M.

Reports FAIR QUALITY

Connection failed due to

FIGURE 22

pre-arranged schedule (unknown to the engineer-operators), calls were entered by a considerable number of Bell System engineers in the vicinity of New York, and calls were initiated from the vessels also by the opening of sealed envelopes carrying instructions to call one or more parties on shore. Figure 22 is a facsimile of the message form or "ticket" used in the operating tests. The table below gives a representative record sheet recording the calls which were made on a particular day and also the time which elapsed in putting each one thru. These data, of course, are not especially representative of what can be done with a system after it is operating smoothly in commercial service, but are interesting in giving a general idea of the way the system worked and in showing that calls were successfully put thru in a reasonably short time. In the aggregate a large number of calls were made, and as a result the system was put to a fairly severe operating test. It was found, as was to be expected, that the time required to put thru the radio connections to the vessels is large in comparison with the connecting time on the wire lines, and will require that precaution be taken in the operating routine to minimize the time during which wire circuits are held up pending connection with the radio link. (The wire circuits used in the tests appeared in New York on a busy P.B.X

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(private branch exchange) and did not receive the operating attention that they would in regular service.) But even tho the radio holding time was larger than the usual wire time, it is in itself rather surprisingly good considering the difficulties which attended this maiden operation of telephone circuits to ships and the operating results must be regarded as full of promise for the extension of telephone service to the highways of the sea.

Tests of Three-Channel Operation

Of course, any comprehensive ship-to-shore radio telephone system must be capable of establishing a number of telephone connections from a common land station to a number of ships. The Deal Beach experiments, therefore, had as one of their objectives the trying out of multi-channel operation. These tests were conducted during the fall of 1920 and thru January 1921, with the S.S "Gloucester" and the S.S. "Ontario." A third boat was simulated by a small-power experimental set installed at the Cliffwood, New Jersey, experimental station. The three channel operation is illustrated diagrammatically in Figure 23, which also shows the scheme of frequencies. The three channels transmitting from Deal Beach were grouped in one frequency range, spaced 30,000 cycles apart. The frequencies transmitted from the ship and received at Deal Beach were grouped in another frequency range removed 30,000 cycles from the first and having frequency intervals likewise of 30,000 cycles. Transmitting and receiving channels differing by 90,000 cycles were paired in the manner indicated to form two-way circuits. While it is possible to squeeze channels together more closely than this, it was not desired in the experiments to go to the limit of frequency squeezing, particularly because of the severe selectivity requirements imposed upon vessel equipment. These frequencies represented a fair balance between technical perfection on the one hand and practically realizable conditions on the other. It will be seen that the set-up was really a four-channel system, with the fourth channel used on 600 meters for calling purposes. Under these conditions three conversations were carried on successfully from the single land station, two to actual ships and one to a "dummy" ship at the Cliffwood experimental station.

Equipping of S.S. "America"

The primary development work of the ship-to-shore system was carried out, as described above, in conjunction with coastal

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DAILY RECORD SHEET—Ship to Shore Radio Service

System Test

April 6, 1921

TELEPHONE CALLS

	From ship	DESTINATION	TOTAL TIME TO CONNECT hr. -in.	DELAYED	INTERRUPTIONS	CANCELLED	COMPLETED UNSATIS-FACTORY	COMPLETED SATIS-FACTORY	REMARKS
1		N.Y.	41					✓	Good.
2		N.Y.	37					✓	Good.
3		N.Y.	16					✓	Good. Weak arc QRM.
4		N.Y.	4					✓	Fair, (weak) bad arc QRM.
5		Newark	3 - 53	P. (11.55 A.M. Cut till P.M. (2.14 P.M. Still out.				✓	Good, (weak RM, spk.)
6		Long Branch	3 - 01	P. (11.53 A.M. Don't ans (2.13 P.M. Answ'd. Party out.				✓	Good, but weak.
7		Asbury Park	2 40	P. 2.19 P.M. Cut.				✓	Fair. RM from 3XM.
8		N.Y.	27					✓	Good.
9		Newark	36	P. 3.00 P.M. Cut of Bldg.				✓	Good, but weak.
10		Asbury Park	-			3.47 P.M. Cut till 5 P.M.			
11		Newark	15					✓	Good. Quite noisy.
12		N.Y.	50					✓	Good. Spk. QRM.
13		Allenhurst, NJ	57					✓	Good. Weak QRM, 3 XM.
14		Asbury Park	29					✓	Good. (Bad spark QRM)
	To ship								
1		N.Y.C.	21					✓	Good.
2		N.Y.C.	45					✓	Good. Ship has spark QRM.
3		N.Y.C.	53					✓	Fair.
4		N.Y.C.	47					✓	Fair.
5		N.Y.C.	-			10.44 A.M; 3.43 P.M; don't ans.			
6		N.Y.C.	19					✓	Good.
7		N.Y.C.	11					✓	Good.
8		N.Y.C.	12					✓	Good. Mr. Maxfield tries out transmitters.
9		Spring Lake	18					✓	Good.
10		N.Y.C.	20					✓	Good.
11		N.Y.C.	2 - 03	P. (2.15 P.M. Not in (2.30 P.M. Will Call.				✓	Good.
12		N.Y.C.	3					✓	Fair.
13		N.Y.C.	-			3.02 P.M. Not there today.			
14		N.Y.C.	26					✓	Fair.
15		N.Y.C.	18	F. 3.30 P.M. Line Busy.	E. 3.50-3.51 P.M. Cut off			✓	Fair.
16		N.Y.C.	8					✓	Fair.
17		N.Y.C.	25					✓	Fair.

TELEGRAMS

	From ship	NO. OF WORDS	TOTAL TIME TO TRANSMIT	ACTUAL TIME TO TRANSMIT	DELAY TO TELEPHONE SERVICE
1					
	To ship				
1		114	13	8	0
2		17	4	1	0

SUMMARY

Total calls	31	Calls completed and satisfactory	28	90.3%
Completed	28	Calls completed and unsatisfactory	0	
Cancelled	3	Calls cancelled due to system failure	0	
Long Distance	0	Calls cancelled not due to system failure	3	9.7%
Toll	1			100%
Local	30			

Average time

Radio A	13.6 mins.
" B	.16 "
Wire A	8.0 "
" B	0

$$\frac{\text{Total minutes operation}}{\text{Total calls}} = \frac{551}{31} = 17.7$$

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vessels. Such vessels were chosen because the rapidity of their turn-round gave much more frequent test periods than could be obtained by means of vessels pursuing a longer route. It remained, however, to equip a trans-oceanic vessel and connect her into the telephone system.

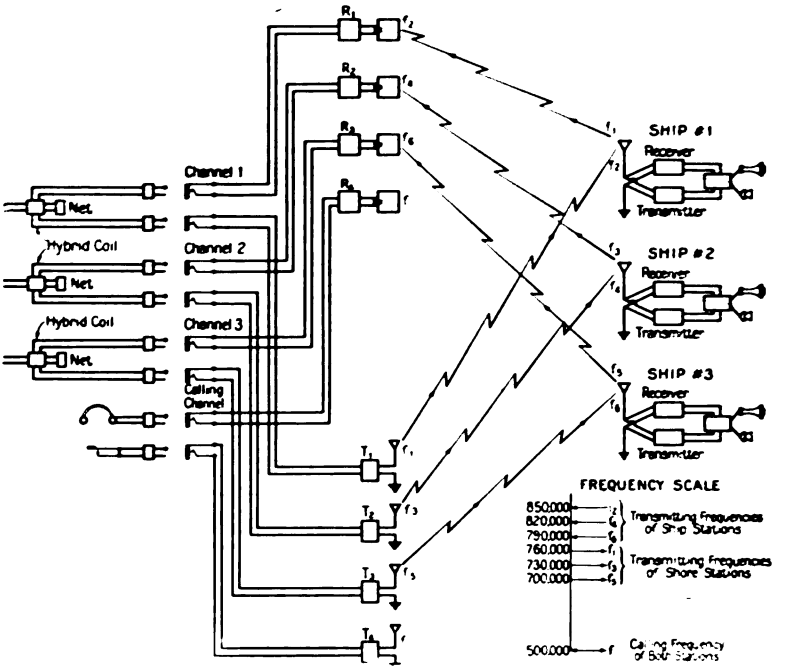

FIGURE 23

In 1921, the development tests of ship-to-shore telephony were extended to include the General Electric Company and the Radio Corporation of America. The engineers of these companies built a ship set similar to that developed in the work described above, but of a more commercial design, and installed in on the S.S. "America" in January, 1922.[3] During the succeeding few months, tests were made between the S.S. "America" and the shore, and on a number of these trips connections were put up to various interested parties around New York when the ship was within about 300 miles (480 km.) of the Deal Beach station. Of course, the "America" was carried out much farther than this at night, but the circuits were not sufficiently reliable

[3]See article "Duplex Radio Telephone Transmitter," by Baker and Byrnes, "General Electric Review," August, 1922.

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to be used in connection with the land lines, as will be appreciated from the field strength measurements given above.

A photograph of a portion of the installation on the S.S. "America" is reproduced in Figure 9 above. The talking tests made with the "America" were the occasion of much interest on the part of the listeners-in, and several of the demonstrations were the subject of newspaper accounts and need not be described. The more technical phases of the tests with the S.S. "America" are (a) the field strength measurements, and (b) the simultaneous telegraph tests discussed below.

Simultaneous Telephone and Telegraph Operation Between Ship and Shore

During the experiments with the Steamships "Gloucester" and "Ontario," the radio telephone transmissions were carried on alternately with the conduct of the regular radio telegraph service of the vessels. Simultaneous operation was impossible because the vessels were equipped with spark transmitters. While this arrangement of having to switch between either telephone and telegraph operation is permissible for small vessels where the communication load is light, it is, of course, not satisfactory for large trans-oceanic vessels where the message business may be such as to require practically continuous operation on the part of both services.

Recognizing, therefore, that one of the problems attending the successful application of radio telephony to large vessels is that of simultaneous telephone and telegraph operation, tests of such transmission were conducted in co-operation with the Radio Corporation of America from the S.S. "America." These were made during February and March of 1922. On the land end, the two radio circuits terminated at different stations, the telegraph end at the Bush Terminal, New York City station of the Radio Corporation, and the telephone at our Deal Beach, New Jersey, station. The telegraph transmitter was of the continuous wave tube type manufactured by the General Electric Company. The telephone and telegraph sets used individual antennas on the ship.

Altho certain apparatus difficulties were experienced aboard the vessel because of the short notice at which the tests were made, nevertheless the tests were successful and demonstrated that a telephone set can be made to operate simultaneously with a suitable C. W. (continuous wave) telegraph transmitter. The final solution of this problem of simultaneous operation, how-

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ever, will undoubtedly require further work in co-ordinating the two types of systems, in order to permit them to be operated on wave lengths relatively close together. During the tests, the wave lengths were widely different, the telegraph operating on about 2,100 meters and the telephone on about 375 meters. The work done at Deal Beach in the development of multiplex telephone operation, where three telephone channels were operated in the vicinity of 400 meters and a fourth channel was operated for telegraphy at 600 meters, demonstrates that it should be feasible to operate telephone and telegraph channels simultaneously on closely adjacent wave length bands. However, in determining wave length allocations, these limiting factors will have to be considered: first, the greater susceptibility of the telephone to interfering noises, such as beat tones, and second the fact that the telephone requires two bands, one for each direction of transmission, and that these bands are required to be spaced a little apart in frequency. It is obvious that by controlling both types of channels from the same station they can be better co-ordinated in respect to frequency and general service use than if operated from separate stations, so that combined telephone-telegraph shore stations present interesting possibilities for the future.

Another method of operation which makes for wave length conservation is that of superimposing the telephone and telegraph channel on the same carrier wave after the general manner of compositing long distance telephone lines with telegraph. This can be done by combining the two channels on one circuit as is done in wire practice and then modulating the combined channels upon the radio carrier. At the receiving end both channels can be detected simultaneously and then the channels separated by composite sets or filters. This method is mentioned to show the ultimate possibilities of combined operation and is not put forward as one which is sufficiently practical, all things considered, for use in the art of the immediate future.

Radio Linked with Transcontinental Line and Catalina Island

The ship-shore radio link was on several occasions connected with very long distance circuits in order to demonstrate the extreme conditions under which combined radio and wire operation are possible.

Perhaps the most interesting case is that in which the ship was linked up with the transcontinental telephone line and con-

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nected thru to Catalina Island in the Pacific thus bringing together the two oceans. The circuit arrangements for one of these demonstrations are given schematically in Figure 24.

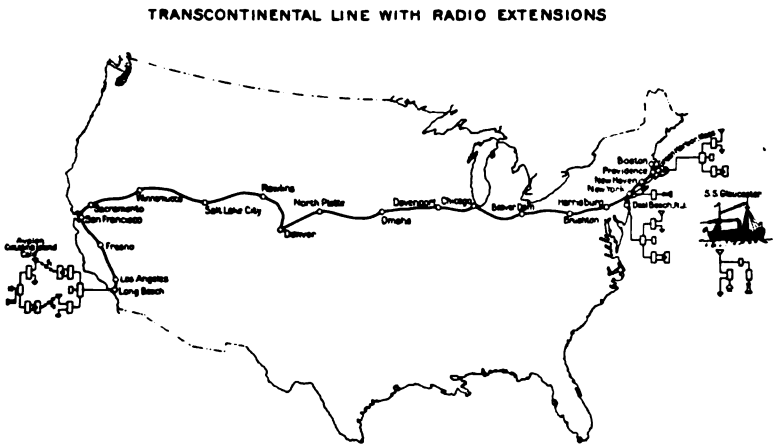

FIGURE 24

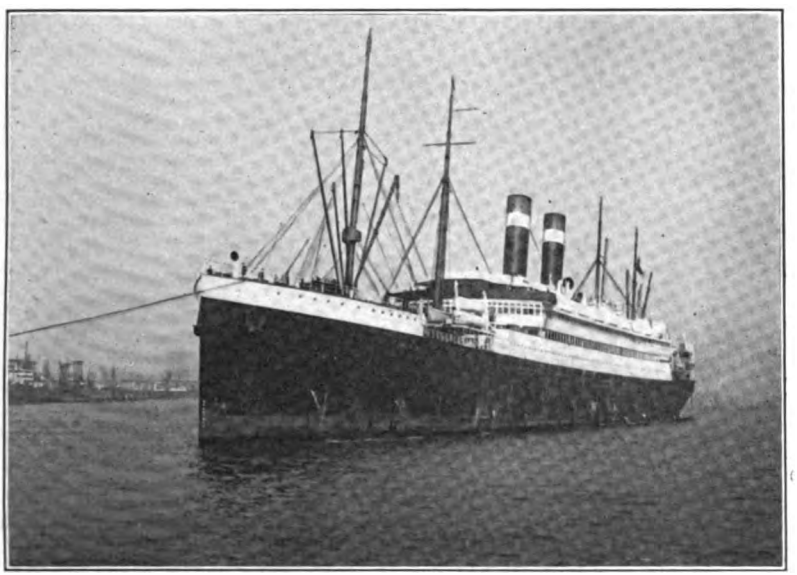

FIGURE 25

Both the Deal Beach and Green Harbor shore stations were used, since it was desired to reach the ship anywhere on her course from Boston to the Delaware capes. The demonstration was,

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therefore, also an example of connecting the ship into the land telephone system thru either of two shore stations. As a matter of fact, at one time the vessel could be reached thru both stations. It happened that the vessel was coming up the coast. The night before the demonstration the ship was communicated with thru the Deal Beach station and connected thru to Catalina Island for a rehearsal. For the demonstration of the following morning, connection was made thru Green Harbor. During both the rehearsal and the demonstration the operator on the vessel talked successfully, altho with some difficulty, with the Catalina Island operator, while New York listened in. This demonstration was made for General J. J. Carty on February 14, 1921. An earlier demonstration of a similar nature, although not involving Green Harbor, was made for the delegates of the Preliminary International Communications Conference on October 21, 1920.

Conclusions

The result of this development may be summed up as follows:

(1) It has realized a radio-telephone system capable of giving two-way transmission and meeting the requirements imposed by joint radio-wire operation.

(2) It has demonstrated the actual use of this radio-telephone system in a wire-radio toll circuit as a means for extending the telephone service of the country to include vessels at sea.

(3) The experiments have demonstrated also the practicability of multi-channel operation from a common land station whereby a number of land subscribers may be connected simultaneously to a number of different vessels.

(4) The transmission and operating tests show the difficulties attending the establishment and maintenance of the radio-telephone link to a moving vessel and the necessity for careful adjustment of the transmission conditions of the circuit and for a diligent maintenance of these adjustments during operation.

(5) In the experiments in multi-channel operation and in simultaneous telephone and telegraph transmission from the same vessel, a beginning has been made in one of the most important problems concerned with the early application of radio telephony to the marine service, namely, that of the co-ordination between radio-telegraph and radio-telephone transmission. It is obvious that the general development of the art of selective transmission, as well as the

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entrance of radio telephony, calls for the use of purer carrier waves and of a minimum transmission band in radio telegraphy.

(6) As regards the important question of wave lengths, the development has shown that the relatively short waves employed in the experiments are satisfactory up to several hundred miles but that for longer distances longer wave lengths will be required. The difficulty of obtaining for the marine service a wave length range sufficiently wide for permitting the handling of any considerable traffic is obvious. The band which can be allocated to this service will naturally be limited by the requirements of other services; and the intensiveness with which this band can be worked by closing up the frequency spacing between channels is limited by the consideration of intercommunication between different types of systems and by apparatus expense.

In general it may be said that the present development has contributed to the communication art the means whereby the universal land line telephone system may be extended to ships at sea. The actual giving of such service must await the working out of the economic problems involved and the necessary business and organization arrangements between the communication companies and the steamship companies.

SUMMARY: The paper describes the development of a two-way radiotelephone system and its use in extending the Bell Telephone System to connect with ships at sea. The electrical considerations and the experimental work involved in determining the system-design of the radio link are discussed. Two land stations were established, one of them a permanent three-channel station on the New Jersey coast. Two coastal vessels and finally one trans-Atlantic liner were equipped. These installations are briefly described in the paper.

The operation of the combined radio and wire system is explained, particularly in respect to the transmission characteristics of the over-all system and the effect thereupon of the movement of the vessel and of variations in atmospheric conditions. Measurements of the variations in the field strength received from field vessels at sea show why it is possible to receive over very long distances at favorable times at night and not during the day. The method of establishing combined radio-telephone-wire circuits to ships is described and representative results are given of the considerable telephone traffic which was handled over the system experimentally during a period of trial operation. Tests of multi-channel telephone operation to several ships thru the Deal Beach shore station, and also tests of simultaneous telegraph and telephone operation from the same vessel are described. Connection of a vessel thru the transcontinental telephone line to the Catalina Island radiotelephone system, whereby the vessel in the Atlantic talked with an island in the Pacific, is briefly described, and finally the outstanding conclusions of the entire development work are given.

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DISCUSSION

A. A. Oswald (by letter): The functioning of the shore station as a repeater connecting the wire and the radio circuits has been described at some length. It may be of interest to consider repeating action of this general kind when applied between two radio circuits, as distinguished from the case of a land wire-radio link.

From time to time, various radio repeater systems have been proposed, in general, analogous to either the 21-type or 22-type repeaters used in long distance wire telephone circuits. The 21-type repeater is one which operates in two directions and employs a single amplifying element. The 22-type repeater operates in two directions and requires two amplifying elements. Each type has certain advantages. The establishment of a number of radio stations for the ship-to-shore experiments afforded an opportunity to test one radio repeater system of each type.

A test was conducted in which the Green Harbor station functioned as a 21-type radio repeater element between the S. S. *Gloucester* and the S. S. *Ontario*. At the shore station, Figure 1, the radio receiver was tuned to 820,000 cycles and the transmitter was adjusted to 730,000 cycles. The shore station transmitter and receiver were then connected together. Both ship transmitters were tuned to 820,000 cycles and both receivers to 730,000 cycles. Thus Green Harbor received both ships on the same frequency and re-transmitted the received signals to both ships.

Altho satisfactory telephone communication was established between the two ship stations, several disadvantages were observed which are inherent to the 21-type repeater. The carrier frequency of the terminal transmitters must be identical to prevent a beat note in the receiving element of the repeater. Carrier noise from both terminal transmitters is simultaneously received at the repeater and re-transmitted, thereby materially increasing the noise level in both terminal receivers. Amplification at the repeater is limited by the strongest incoming signal, since the adjustment must avoid overloading the transmitter. Amplification at the repeater is also limited by the electrical relation between the receiver and transmitter, which must be such that an oscillatory or singing condition is not established. If the four-wire termination is replaced by a two-wire termination, such as would be required if connections were made to the regular ship

*Received by the Editor, March 16, 1923.

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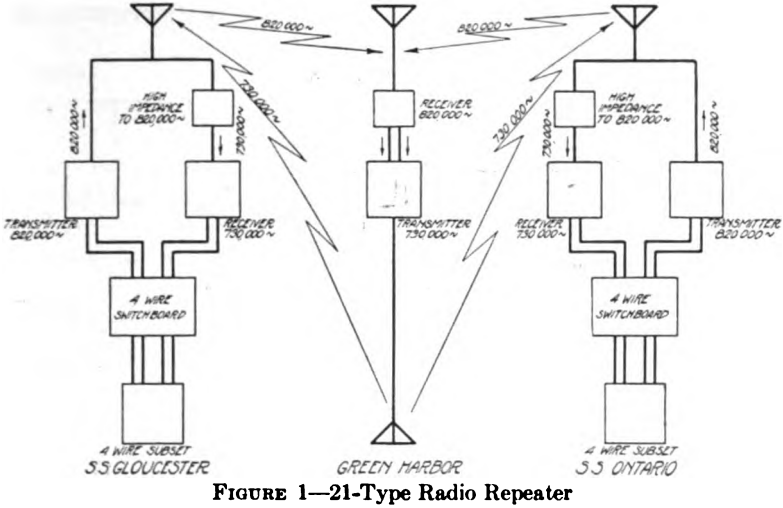

FIGURE 1—21-Type Radio Repeater

telephone system, a careful adjustment of amplification is necessary at all points in the system in order to avoid undesired and destructive oscillations. Obviously a similar condition arises when two or more repeaters are introduced in the radio circuit.

A similar test of a 22-type radio repeater was conducted at the Deal Beach Three Channel Station. In this case, four frequencies were employed and the repeater had two separate transmitters and receivers. Two complete channels at Deal were used to form the repeater element between the S. S. *Gloucester* and a five-watt transmitter at Cliffwood, N. J. (Figure 2).

The principal disadvantages of the 22-type repeater are the cost of two transmitters and two receivers as against half this equipment for the 21-type, and the use of four frequency bands as aganist two bands for the 21-type. On the other hand, it was found that the 22-type radio repeater not only eliminated the undesirable features of the 21-type, but also had marked advantages. Since the terminal transmitters operate at widely different frequencies an audible beat note is not produced in the receiver units of the repeater. Carrier noise is confined to one channel. The amplification in the east and west circuits is not limited by the repeater units except in the matter of overloading. Two or more radio repeaters may be introduced in the radio circuit without additional difficulties. Two-wire terminations are subject to the usual hybrid-coil limitations and do not involve any new considerations except precautions to avoid overloading the radio transmitter. Free oscillations or singing will only occur

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CONTINUOUS-WAVE RADIO TRANSMISSION ON A WAVE LENGTH OF 100 METERS, USING A SPECIAL TYPE OF ANTENNA*

By

Francis W. Dunmore

(Associate Physicist, Bureau of Standards, Washington, D. C.)

Introduction

The use of short wave lengths, of the order of 100 meters, for radio transmission, has numerous advantages. However, comparatively few investigations have been made of transmission on 100 meters, with either damped waves, or continuous waves, or radio telephony. This paper describes a method of continuous-wave transmission on a wave length of 100 meters, using a special type of antenna. This investigation was undertaken at the request of the Office of the Chief of Air Service, United States Army. The Office of the Chief of Air Service, and the Office of the Chief Signal Officer, United States Army, have given their consent to making public the results of this investigation.

In the investigation here described, communication was carried on using continuous waves, interrupted continuous waves and radio telephony. An electron tube generating set, rated at about 200 watts, was used. The antenna was especially designed for use on a wave length of about 100 meters. Most of the tests here described were conducted on a wave length of 105 meters. A special type of receiving set, suitable for 100 meters, was developed for this work. This paper gives sufficiently detailed information so that anyone having suitable radio experience can construct and operate similar apparatus, and continue in this line of investigation.

The use of short wave lengths is advantageous in that it reduces interference in several different ways. At the present time, very few stations transmit on waves having such short wave lengths as 100 meters. For communication by radio

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telephony, a much narrower band of wave lengths in meters is required when transmitting on 100 meters than when transmitting on longer wave lengths such as 300 meters or above.

The use of short waves such as 100 meters also reduces, in two ways, the difficulties in reception due to strays or "atmospherics." It has been observed that more serious strays are encountered in reception with an antenna of large dimensions than with an antenna of comparatively small dimensions. For reception on 100 meters, a small antenna can be used. It has been found suitable to use a loop antenna (single-turn coil antenna) about 10 feet (3.2 m.) on a side, for reception on 100 meters, and with such a small antenna difficulties due to strays are reduced. Furthermore, even if a large antenna is used, it has been observed that strays are usually not so serious when a receiving set is tuned to 100 meters as when it is tuned to longer wave lengths. An interesting application of the use of a wave length of approximately 100 meters has recently been reported to have been made by the Westinghouse Electric and Manufacturing Company. The report states that Cleveland, Ohio, is located in a so-called "dead spot" with respect to 360-meter broadcasts from KDKA in Pittsburgh, Pennsylvania. It was found that this dead spot did not exist when wave lengths of 100 meters were used. Broadcasts of KDKA were made simultaneously on approximately 360 and 100 meters. The 100-meter signals were received clearly in Cleveland, and were re-broadcast on 360 meters from a broadcasting station in Cleveland. The local listeners in Cleveland were therefore enabled to hear KDKA on their 360-meter receiving sets.

The antenna here described has a directional characteristic somewhat like the combination of a coil antenna and a vertical antenna and can be directed to transmit the strongest signals in a certain general direction. The antenna described is, however, not so markedly directive that it is not suitable for broadcasting in all directions over moderate distances.

Generating Set

The circuit of the generating set used, as well as the antenna, is shown in Figure 1. There is a tuned-plate primary circuit, with a coupled antenna circuit. Four Western Electric Type G-tubes, rated at 50 watts each, were used in parallel. The tubes were found to operate more satisfactorily by connecting in the grid circuit an inductively wound resistance of 3,200 ohms shunted by a 0.002 microfarad condenser. A 50-ohm resistance

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was connected in the high-voltage supply circuit, and helped to stabilize the operation of the tubes. For operation at 105 meters, it was found that the primary or plate coil *B* (Figures 1 and 3) should consist of two turns of heavy copper strip two inches (5.08 cm.) wide. This coil, shunted by a mica transmitting condenser having a capacity of 0.002 microfarad, gave a natural wave length of the primary circuit of about 105 meters.

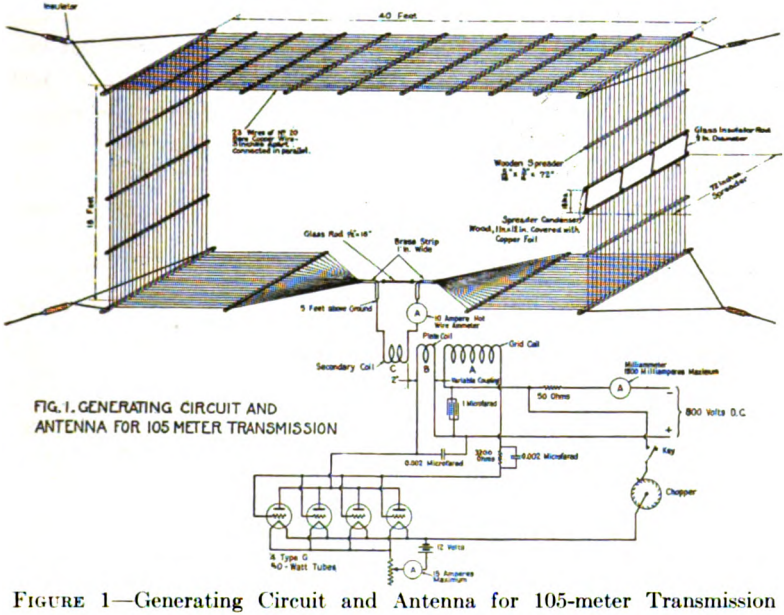

FIG. 1. GENERATING CIRCUIT AND ANTENNA FOR 105 METER TRANSMISSION

FIGURE 1—Generating Circuit and Antenna for 105-meter Transmission

For the grid coil *A*, a helix of 14 turns was used, as shown in Figure 2. The helix was made of half-inch (1.27 cm.) copper strip, had a diameter of ten inches (25.4 cm.) and a spacing between adjacent turns of five-sixteenths of an inch (0.079 cm.) A tap at five and one-half turns from the center gave best reception. The coupling between this coil and the plate coil *B* was rather critical.

The generating circuit was coupled to the antenna by a secondary coupling coil *C*, which is shown in Figure 4. This coil consisted of three turns of brass strip, one inch (2.54 cm.) wide, and was connected in series with the antenna.

Figure 5 shows the generating set as assembled in an experimental setup, including the grid coil *A*, the plate coil *B*, and the secondary coupling coil *C*.

While the generating set described above was arranged espe-

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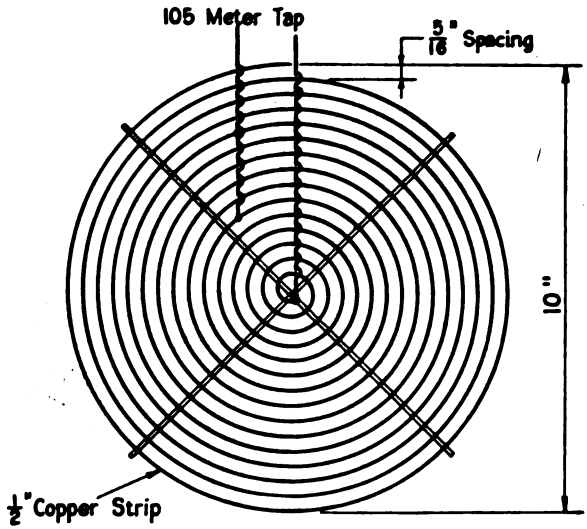

FIGURE 2—Grid Coil for Transmitting Set

cially for use with the antenna here described, the same generating set can be satisfactorily used with a T, L, fan, or other usual type of elevated antenna.

In conducting communication on interrupted continuous waves, a chopper was used, which was connected in the lead from the filament to the radio-frequency circuit, as shown in Figure 1.

It is important to keep the frequency of the generating set

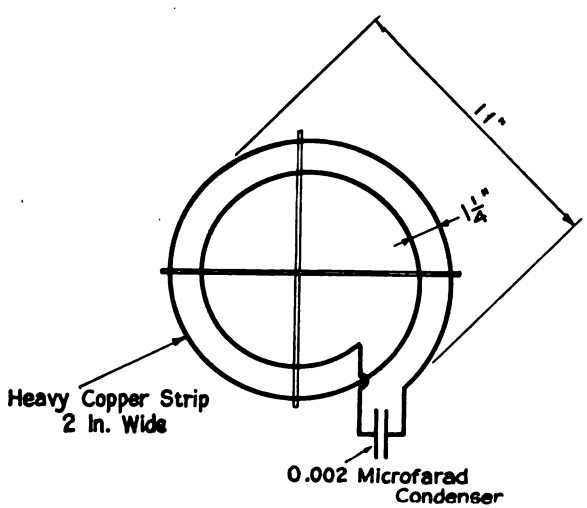

FIGURE 3—Plate Coil for Transmitting Set

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constant, since slight changes of frequency will require frequent adjustments of tuning at the receiving station, and a small change of frequency of the transmitting set may cause the receiving station to lose the transmitting station. During opera-

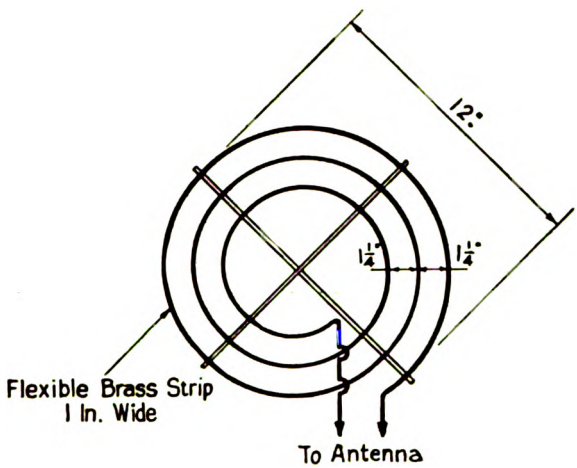

FIGURE 4—Secondary Coupling Coil

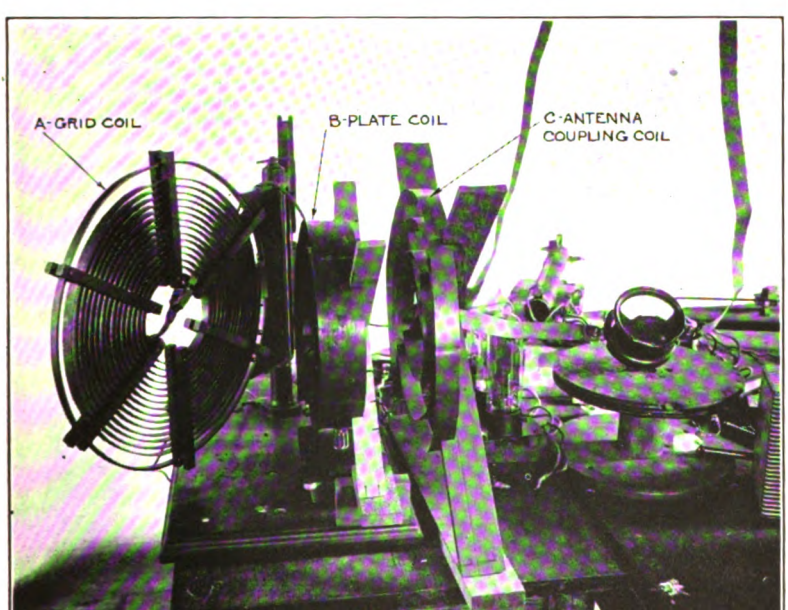

FIGURE 5—Assembled Generating Set

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tion, the operator should not get near the helix of the transmitting set, or other parts of the circuit carrying radio-frequency current.

Antenna

The antenna used was especially constructed with a view to reducing ohmic resistance and to obtain the maximum radiation on the wave length used. It had both localized and distributed capacity, and is shown in Figure 1. The antenna as erected and the small operating building containing the generating set is shown in Figure 6. It consisted of 23 number 20 Brown and Sharpe gauge bare copper wires* connected in parallel and spaced three inches (7.62 cm.) apart, which formed a rectangle 18 feet

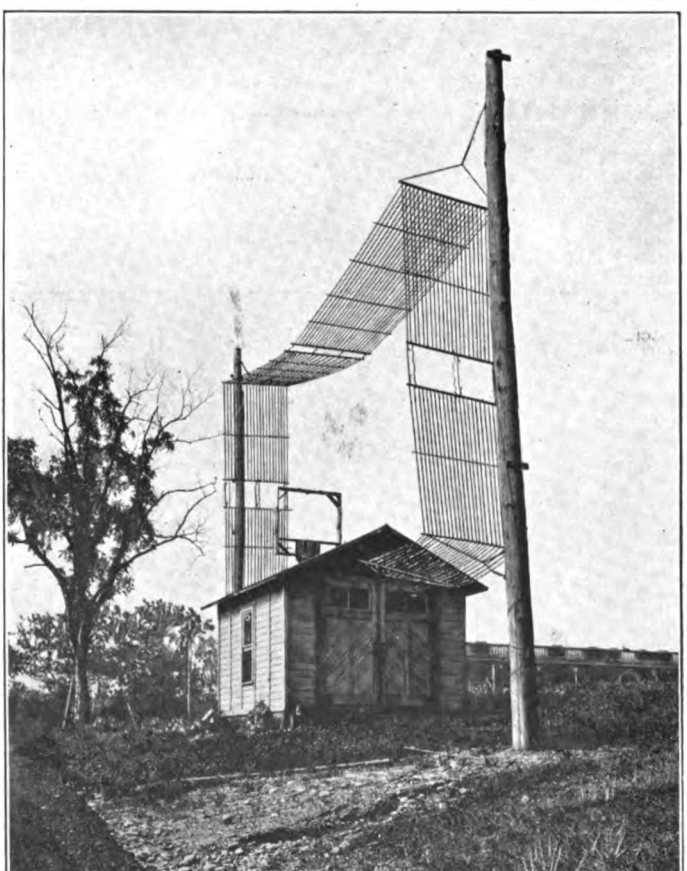

Figure 6—Special Type of Antenna for Transmission on 105 Meters, Consisting of 23 Turns in Parallel

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(5.5 m) high and 40 feet (12.2 m.) long. The antenna was supported from two poles. Light wooden spreaders six feet (1.85 m.) long were placed about every four feet (1.2 m.) in order to keep the wires separated. The generating set is coupled to the antenna at the middle of the lower side of the antenna, by means of the secondary coupling coil *C* shown in Figure 4. The 23 wires did not form a complete circuit, but had a gap of about 18 inches (0.46 m.) Different locations of this gap were tried. The two spreaders at the gap on which the wires terminated were held together by glass rods bent so as to have hooks on each end. The two spreaders at the gap were covered with copper foil connected to all of the wires, and a condenser having long narrow plates widely separated from one another was thus formed by spreaders. The capacity of this gap condenser was small, but was of the proper value to give a natural wave length of 105 meters to the antenna as constructed.

Figure 6 shows three such condenser gaps which were constructed for experimental purposes. During any particular test, two of these three condensers were short circuited by jumper wires shown in the photograph, so that there was only one condenser in the antenna at a time.

One advantage of this type of antenna is that it can be made very rigid, so that its natural wave length will vary very little even when fairly strong winds are blowing. This is an important advantage since with the ordinary **T** or other form of elevated antenna, considerable variations in the transmitted wave length are often caused by wind blowing the antenna around and thus varying its capacity. Another advantage in this particular type of construction is the fact that a number of parallel wires spaced have a lower radio-frequency resistance than when bunched together even tho each wire is insulated.

Receiving Set

A special receiving set suitable for wave lengths from about 75 to 175 meters was developed for use during tests made at Washington. The circuit diagram of this set is shown in Figure 7, and the assembled receiving set is shown in Figure 8.

This set was designed for use with a single-turn coil antenna. It consists essentially of one stage of radio-frequency amplification employing a tuned plate circuit, a detector, and two stages of audio-frequency amplification. The plate circuit tuning element

*Diameter of number 20 Brown and Sharpe gauge wire = 0.0312 inch = 0.081 cm.

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G (Figure 7) in the plate circuit of the first tube is made by winding 125 turns of number 38 double-silk covered wire* in a single layer on one end of a piece of square insulating tubing 3¾ inches (9.5 cm.) long, having an inside diameter of one-half inch (1.27 cm.) and an outside diameter of five-eighths of an inch (1.59 cm.).

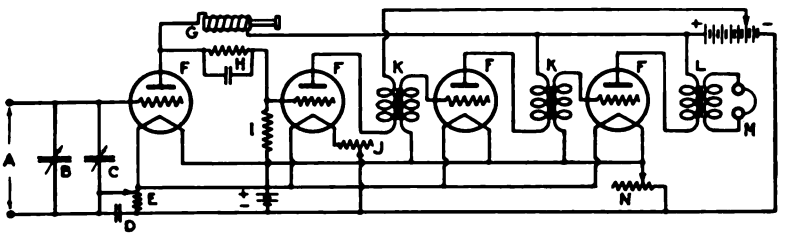

FIG. 7. RECEIVING SET FOR 75 TO 175 METERS

A. TERMINALS FOR CONNECTION TO COIL ANTENNA
B. 0.0005 MICROFARAD TUNING CONDENSER
C. TWO-PLATE VERNIER CONDENSER
D. 0.002 MICROFARAD CONDENSER
E. 300 OHM STABILIZING RESISTANCE
F. RECEIVING TUBES
G. PLATE TUNING DEVICE
H. 2 MEGOHM GRID LEAK, 0.0002 MICROFARAD CONDENSER
I. 1-MEGOHM GRID LEAK
J. DETECTOR TUBE FILAMENT RHEOSTAT
K. AUDIO FREQUENCY TRANSFORMERS
L. TELEPHONE TRANSFORMER
M. TELEPHONE RECEIVERS
N. FILAMENT RHEOSTAT

FIGURE 7—Circuit Diagram of Receiving Set for 75 to 175 Meters

For tuning, a movable iron core is used, which consists of laminations 0.001 inch (0.0025 cm.) thick built up into a core seven-sixteenths of an inch (1.34 cm.) square and two inches (5.08 cm.) long.

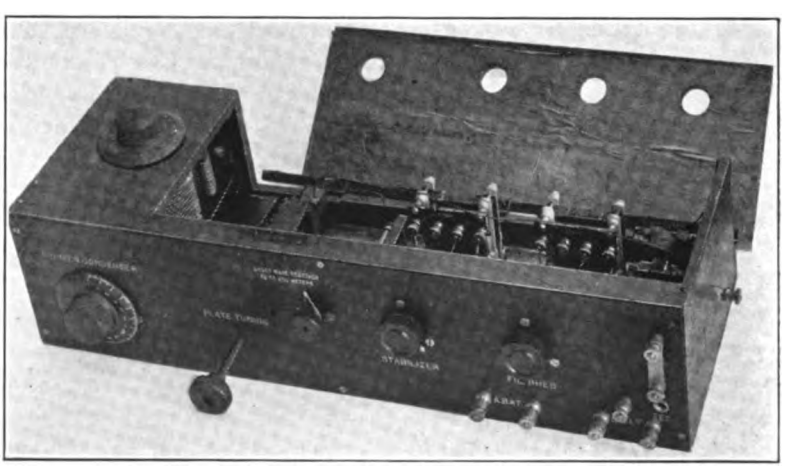

FIGURE 8—Assembled Regenerative Receiving Set for 75 to 175 Meters, for use with Coil Antenna

*Diameter of number 38 wire = 0.0039 inch = 0.010 cm.

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Transmission Tests

Numerous tests have been made with this type of transmitting set in connection with the type of antenna described.

In May and June, 1922, transmission tests were conducted from Washington, D. C., to Pittsburgh, Pennsylvania, to determine the variations of signal intensity from daylight to darkness on a wave length of 105 meters. In November, 1922, tests were conducted at McCook Field, Dayton, Ohio, with the type of generating set and antenna above described located on the ground and a receiving set located on an airplane, to determine the directional characteristics of this type of transmitting antenna.

Tests at Washington—Reception on Ground

The tests in May and June were conducted with station 8XK at East Pittsburgh, Pennsylvania, which is operated by Frank Conrad, of the Westinghouse Electric and Manufacturing Company. Communication was conducted, using unmodulated continuous waves, interrupted continuous waves, and radio telephony. Two-way communication was usually maintained during both daylight and darkness.

The receiving set at Pittsburgh employed an electron tube detector and one stage of audio-frequency amplification. When the transmitting set at Washington was putting about 4.8 amperes at 105 meters into the antenna, the signal received at Pittsburgh had an aubibility which varied somewhat, but on the average was about 100. One important purpose of these tests was to investigate the phenomena of transmission over land on a wave length of 105 meters, with special reference to variations of signal intensity from daylight to darkness. On two different days tests were conducted from 12 o'clock noon to 9:00 p. m., and both continuous wave and interrupted continuous wave signals were transmitted every fifteen minutes for a period of five minutes. It was found that the received signals transmitted during daylight on 105 meters were nearly as strong as those transmitted at night. On one day, the signals received at Pittsburgh had an audibility of 170 at 3:30 p. m., when the sun was shining brightly at Pittsburgh, while previously that day during cloudy weather the audibility had been 100. The general audibility observed during all the tests on 105 meters probably did not vary any more than would occur in ordinary commercial transmission on such wave lengths as 600 meters. The observed audibility of the received signal for interrupted continuous waves

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was, roughly, about one-half that of the received signal for unmodulated continuous waves. The fading often observed during radio communication on 200 meters, especially at night, was notably absent during these tests on 100 meters.

The May and June tests would indicate that in transmission on 100 meters serious fading does not occur, and that the usual marked difference in transmission between daylight and darkness is absent, altho these particular tests were not sufficiently extensive to be conclusive on these points.

The plane of the antenna at Washington made an angle of about 45 degrees with respect to the line of direction to Pittsburgh, so that the signals observed at Pittsburgh do not represent the best transmission of which the transmitting set is capable over a distance of 200 miles (320 km.). Experiments were made using the antenna with the condenser gap in the middle of the top side, and also with the condenser in the middle of each of the vertical sides. With the condenser in the top side, the antenna had a radiation characteristic very similar to that of the usual form of coil antenna, except that complete extinction of the signal was not obtained. With the condenser gap in a vertical side, a somewhat uni-directional characteristic was obtained, the best transmission being in the direction of the open side. Altho the tests were not conclusive, maximum distance range was obtained when the condenser was in a vertical side.

Tests at Dayton—Reception on Airplane

In November, 1922, tests were conducted at McCook Field, Dayton, Ohio, for the purpose of determining the directional characteristic of this type of transmitting antenna, and further to test the performance of the 100-meter transmitting set The Engineering Division of the Air Service, United States Army, conducts experimental work at McCook Field, and these tests were made in co-operation with representatives of the Air Service. All the Dayton tests were made, using interrupted continuous waves. Signals were sent from the transmitting set and antenna located at McCook Field, and received on an airplane in flight.

In the apparatus as installed at McCook Field, a 40-volt "C" battery was used in place of the grid leak shown in Figure 1. Three 50-watt power tubes were used. An ammeter indicated an antenna current of 5 amperes with continuous waves and 2.5 amperes with interrupted continuous waves.

For reception on the airplane a 60-foot (18.3 m.) trailing wire

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was used with a 7½ lb. (3.4 kg.) weight. This short wire and heavy weight caused the antenna to maintain an approximately vertical position and gave the antenna a receiving characteristic which was only slightly directional. For receiving at Dayton, a Signal Corps Type SCR-69 set was used, the coils being rewound for 100 meters. This set is of the direct-connected non-regenerative type consisting of a detector and two stages of audio-frequency amplification.

Tests were first made with the condenser gap in the center of the top horizontal section of the antenna. The airplane made a circle of three miles (4.8 km.) radius around the transmitting antenna, at an altitude of 2,000 feet (610 m.). It was noted that the signals were very strong along the plane of the antenna and very weak at right angles to the plane of the antenna. The effect was similar to transmission from a coil antenna combined with an ordinary elevated antenna, that is, a figure-of-eight characteristic without sharp minimum was obtained. When flying over the antenna at right angles to its plane and about 800 feet (240 m.) above it, two dead zones were noted, one just before being directly over it, and the other just after passing over it.

The antenna was then connected with the condenser gap in the center of one of the vertical sides. A second flight similar to the one mentioned above was made. The transmission characteristic seemed to be similar to the figure produced by the print of a shoe, the antenna being located at the instep. The signals were, on the whole, louder than in the first test in which the condenser was in the horizontal side of the antenna. Maximum radiation took place from the end of the antenna in which the condenser was placed.

Figure 9 shows the course taken in a third flight in order to determine the range in the general direction of maximum radiation. An altitude of 4,000 feet (1,220 m.) was held during this flight. It was found that as the airplane flew in a direction forming an angle of about 40 degrees with respect to the plane of the transmitting antenna, that the signal was lost at 11 miles (17.6 km.). The airplane than continued for a couple of miles and made a turn flying at right angles to the plane of the transmitting antenna in order to cross the plane of maximum radiation. For a distance of one and one-half miles (2.4 km.) on each side of the plane of the coil, the signals could be clearly heard. This was at a distance of 13 miles (20.8 km.). This distance, over which the signals could be heard, increased as the source was approached.

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At 14 miles (22.4 km.) a similar region over which signals could be heard was found.

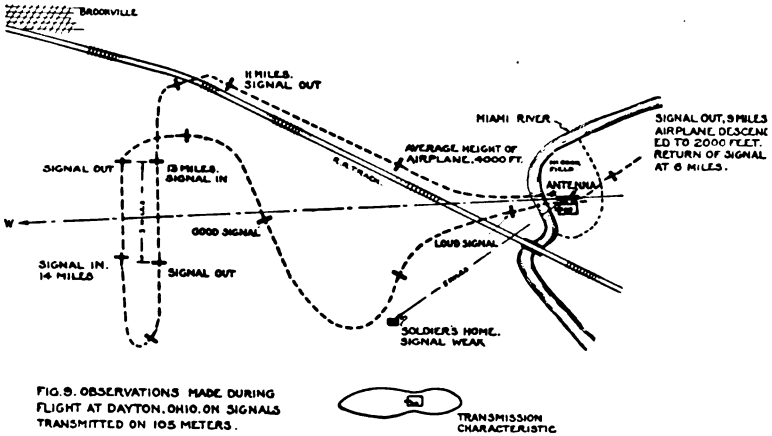
BROOKVILLE
11 MILES. SIGNAL OUT
MIAMI RIVER
SIGNAL OUT, 9 MILES AIRPLANE DESCENDED TO 2000 FEET. RETURN OF SIGNAL AT 6 MILES.
AVERAGE HEIGHT OF AIRPLANE, 4000 FT.
SIGNAL OUT
13 MILES. SIGNAL IN
ANTENNAE
W
GOOD SIGNAL
LOUD SIGNAL
SIGNAL IN. 14 MILES
SIGNAL OUT
SOLDIER'S HOME. SIGNAL WEAK
FIG. 9. OBSERVATIONS MADE DURING FLIGHT AT DAYTON, OHIO, ON SIGNALS TRANSMITTED ON 105 METERS.
TRANSMISSION CHARACTERISTIC

FIGURE 9—Observations Made During Flights at Dayton Ohio, on Signals Transmitted on 105 Meters

A flight was next made in the opposite direction at a similar angle with respect to the plane of the antenna. The signal was lost at nine miles (14.4 km.). The altitude was then decreased to 2,000 feet (610 m.) and a return course taken. The signal was not picked up again, at this altitude, until the airplane was within six miles (9.6 km.) of the transmitting station. The fact of greater signal strength at greater heights has been noted by Franklin[1] and others, when using wave lengths of three meters, with a reflecting arrangement. The tests described by Franklin were made near the sea, and at an altitude of 100 feet (30.5 m.) the signal strength was about seven times what it was at sea level.

The short-distance range obtained in these tests at Dayton were probably due to the fact that a receiving set of comparatively low sensitivity was used. In the previous tests made between Washington and Pittsburgh, a receiving set of considerably greater sensitivity was used, and much greater distances were covered.

CONCLUSION

The investigations which have been described show that it is entirely practical to get good daylight communication over a distance of 200 miles (320 km.), using the generating set and the

[1] C. S. Franklin, "Short-wave Directional Wireless Telegraphy," "Wireless World and Radio Review," volume 10, pages 219-225, May 10, 1922.

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special type of antenna described. The use of the method described appears to have particular advantages for daylight communication.

The type of antenna here described has been found to have the same general kind of directional characteristic as the more usual type of receiving coil antenna used in conjunction with an ordinary elevated antenna.

ACKNOWLEDGMENT—Assistance in the course of this investigation has been rendered by Mr. Francis H. Engel. The author also wishes to acknowledge his indebtedness to Mr. Frank Conrad and his associates for their co-operation and assistance in conducting the transmission tests between Washington and Pittsburgh.

Department of Commerce,
March 5, 1923 Washington, D. C.

SUMMARY: The paper describes a method and apparatus for continuous-wave transmission on a wave length of 105 meters. An electron tube generating set was used which employed four 50-watt tubes in a tuned-plate primary circuit, coupled to the antenna circuit. The antenna was rectangular in shape, 18 feet (5.5 m.) high by 40 feet (12.4 m.) long, and consisted of 23 wires connected in parallel. The generating set was coupled in on the lower side, and a gap which constituted a condenser was inserted in one of the other sides. The primary circuit and the secondary circuit separately each had a natural wave length of about 105 meters. A special receiving set was developed for this short-wave work. In transmission tests conducted between Washington and Pittsburgh, good signals were received in Pittsburgh during daylight, with 4.8 amperes in the transmitting antenna. Comparatively little variation in transmission was noted from daylight to night, and fading was not so serious as might be expected for somewhat longer wave lengths. The method described would, therefore, seem to have particular advantages for daylight communication. Tests were made at Dayton, Ohio, in transmitting with this set from the ground to an airplane in flight, and directional characteristics of the antenna were determined with the condenser gap in the top side of the antenna, and also in one of the vertical sides.

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PROGRESS IN RADIO ENGINEERING IN RUSSIA 1918-1922*

By

Valerian Bashenoff

(Member and Secretary of the Institute of Russian Radio Engineers, Moscow, Russia)

1. During the period of the blockade, Russian radio engineers were almost entirely cut off from the remainder of the civilized world. Only on rare occasions were they able to learn of progress in radio engineering in foreign countries thru intercepted radio telegrams or a casual number of an engineering journal or newspaper. Consequently until 1921 it was necessary for them to utilize to the utmost in their engineering activities all the creative ability along theoretical and experimental directions which was available in Russia under the existing circumstances. The purpose of this paper is to convey to the West European and American scientific world some information relative to the technical progress in radio communication which was carried out. It should be mentioned that during the period from 1918 to 1921 all radio engineering work in Russia was necessarily carried out by Russian scientists and engineers, with complete isolation from scientific work done abroad, and under very difficult circumstances and disturbed conditions of the industrial enterprises in Russia. Most of the material of this paper comes from the proceedings of meetings of the Institute of Russian Radio Engineers and from the data of the Russian Patent Committee for Research. Everything dealing with the field of military radio engineering has been omitted from this paper.

All scientists and engineers in Russia who are working in the field of radio engineering have associated themselves in a private scientific and engineering society (The Institute of Russian Radio Engineers), which was founded in March 31, 1918, by thirty-four such scientists and engineers. This society, chronologically considered, is the third organization of this sort in the history of the world. It now has approximately two hundred members. The

* Received by Editor, September 22, 1922. Translated from the German by the Editor.

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headquarters are in Moscow, and sections have been formed in the following cities: Petrograd, Nijni-Novgorod, Kieff, and Odessa. The Institute of Radio Engineers is also the parent organization of the Radio Engineering Society of Turkestan. Since 1919, the President of the Institute of Russian Radio Engineers has been Professor M. W. Schuleikin, of the Moscow Institute of Technology, and the author has been the Secretary since 1919.

The individual activities of the members of the Institute will be described below. As indicative of the activity of the Institute it may be stated that regular meetings are held in Moscow and Petrograd weekly.

The radio laboratories of Russia, in order to co-operate better in their common scientific activities, have formed a "Radio Association" which was a portion of the scientific-technical division of the Superior Industrial Council of Russia. The Institute of Russian Radio Engineers is an affiliated organization of the "Radio Association." There has, therefore, existed in Russia since June, 1921, an organization which thruout this country has almost the same tasks as the International Union for Scientific Radio Telegraphy (U. S. R. I.). The President of the "Radio Association" is Professor A. A. Petrowski at Petrograd, the Vice-President, Professor M. W. Schuleikin, of Moscow, and the author is the Honorary Secretary.

2. It is correct to state that the electron relay during recent years has been the most important subject for research in all foreign radio engineering. In 1917 it was called to our attention in the form of three-electrode tubes in the French amplifiers, and aroused no slight interest among Russian radio engineers. Engineer M. A. Bontsch-Bruewitsch was the first to build up an organization in Russia for the production of these tubes for receivers and amplifiers in military and long distance radio stations, this work being carried out in the shops of the radio station at Twer, where he was then stationed. After the establishment of the Radio Laboratories of the People's Commisariat of Posts and Telegraphs at Nijni-Novgorod, Mr. Bontsch-Bruewitsch transferred his activities to the new location and busied himself with a quantity production of tubes (type P. R. I. tubes for receiver and amplifier uses). Mr. Bontsch-Bruewitsch originated a whole series of constructional improvements which have been patented in Russia and which include a spring suspension arrangement to avoid mechanical shocks to the tubes, and grids with two external terminals by means of which the

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grid can be brought to incandescence during the evacuation process. The scientific work of this engineer in the production of very great quantities of these tubes is of special interest (see the Russian journal, "Radio Engineering," number 7, August, 1919). When we became acquainted in 1921 with the theoretical results, in the same field, of the German and English scientists, we found that their fundamental notions were in good accord with the conclusions reached by Mr. Bontsch-Bruewitsch as early as 1919, altho he had reached his results from quite a different point of view (see "Theory of the Triode" by Professor Bontsch-Bruewitsch, Russian journal "Radio Telegraphy and Telephony," number 10, 1921). The first samples of these tubes were used in the Russian radio stations in 1919, and until 1922 the shops of the Radio Laboratory at Nijni-Novgorod were the only source of receiving tubes for all the Russian Stations. At the end of 1921, Professor M. M. Bogoslowski organized the quantity production of tubes in his shops at the First Polytechnic Institute at Petrograd. He used as a model for these tubes the French triodes, but with small improvements in construction. Professor Tschernischoff organized the production of receiving tubes of somewhat different type from those of Professor Bogoslowski at the radio laboratory of the Polytechnic Institute at Petrograd. Since the beginning of 1922 the National Shops at Odessa have been delivering amplifier tubes of special construction. In the field of the manufacture of transmitting tubes for large outputs, the good work done by Professor Bontsch-Bruewitsch and Professor A. A. Tschernischoff deserves notice. The former has produced transmitting tubes for large outputs with water-cooled anodes at the laboratory at Nijni-Novgorod. These tubes have the following original construction. They consist of a copper tube into which four mutually perpendicular contact fins are soldered, thus producing chambers. In each chamber a filament as well as a grid are fastened on a glass rod. This arrangement permits excellent cooling of the anode and raises the output which can be obtained from the tubes. Tubes of this sort for each output were used by Professor Bontsch-Bruewitsch in the radio-telephone station at Moscow and have given excellent results. He succeeded, by the end of 1922, in producing 2-kilowatt tubes using a new construction, without water-cooled anodes.

Professor A. A. Tschernischoff had begun the manufactu er of high-powered transmitting tubes and rectifiers in 1918 at the radio laboratoty of the Polytechnic Institute in Petrogra d.

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In these, to heat the cathode, a discharge is caused to pass by means of a definite constant electromotive force between an auxiliary cathode and the main cathode. The anode consists of a platinum vessel which is placed around a glass tube. Water is circulated steadily in this glass tube. This water circulation reaches the points of greatest development of heat. By making the metallic walls sufficiently thin, excellent cooling is obtained and it becomes possible to increase the output of transmitting tubes. At the beginning of this research, the investigator had to solve a great number of technical problems which took considerable time. The chief problem was to maintain a high vacuum ($10^{-6}-10^{-8}$ mm.). It was not until 1921 that such vacuum was obtained thru special devices. One device which deserves particular notice is a new type of mercury condensation pump built according to the ideas of Professor A. A. Tschernischoff and Miss J. K. Schmidt. The most characteristic feature of this pump is the condensation of the mercury vapor on a water-cooled metallic wall which is connected to the other glass portions of the pump by a platinum cylinder with thin walls.

3. The best results in the utilization of tubes of small and large output in Russia have been obtained in two forms of radio telephone transmitter, one of which was discovered by Mr. A. T. Ugloff and the other by Professor Bontsch-Bruewitsch. Mr. Ugloff worked out his circuit in a practical way at the Second Military Radio Depot of the town of Kasan, and described the results at a meeting of the Institute of Russian Radio Engineers on February 8, 1919. He had aimed at obtaining speech modulation of radio frequency without the use of a microphone capable of withstanding high power. The result was obtained by the use of a cascade amplifier which amplifies the modulated radio frequency current produced in the first oscillatory circuits by an attached microphone. It was characteristic of this amplifier arrangement that it was very sensitive to alterations in the microphone resistance. The investigator had at his disposal only low-power tubes of French manufacture intended for amplifier and receiver purposes. In order to increase the total antenna power he added more tubes in each step; in fact the number of tubes in each step could be made eight or ten times greater than that in the preceding. These tubes had a filament voltage of six volts and 300 to 320 volts in the plate circuit. In most of his experiments he used only three tubes in the first stage, 12 in the second and 84 in the third. Experiments in radio telephony using this system were carried out in

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July, 1920, between the Volga Steamer *Radishteff* and the Radio Station of the Second Military Depot at Kasan, and lead to the result that satisfactory two-way communication was possible between the steamer and the station at Kasan over the entire distance from Kasan to Zarizen. From this point on, the radio telephonic communication was only one-way, the station at Kasan being unable to hear the steamer altho the steamer could hear Kasan as far as Astrachan, 1,100 km. (690 miles) in a straight line from Kasan. In order to establish communication over this distance, continuous waves were used by the steamer which were well received at Kasan. The same circuit using 35 French tubes permitted complete reception in Kasan with a six-step amplifier (model 1 constructed by A. W. Dikaroff) at a distance of 500 km. or 300 miles, with a low antenna on the steamer. Even better results were obtained with this radio-telephone set on the steamer *Dekabrist* in 1921.

Mr. A. T. Ugloff, of the Military Radio Engineering Laboratories, installed receiving stations on moving trains in 1918, and, in 1920, obtained good results in transmission from moving trains. One of the fellow-workers of Mr. Ugloff, Mr. S. W. Witkewitsch, built a radio telephone set for airplanes using the same circuit and obtained good results.

Professor Bontsch-Bruewitsch constructed high power radio telephone stations in quite a different way. He used in his circuit high power tubes of the construction mentioned above, and record ranges were obtained in tests during 1920. One of his tubes operating on low-plate voltage was used for producing continuous oscillations. These were modulated by means of a second tube placed in parallel with the first. The modulated oscillations were then amplified by a tube and transferred to the grids of six tubes in parallel which fed the antenna circuit. The maximum antenna current, using 3,000 volts in the plate circuit, was 30 amperes. This corresponded to an output of 5 kw. in the antenna of the old station at Moscow with a mast height of 120 meters (394 ft.). Long distances were covered by this transmitter. The most distant stations which received the speech with three-step audio frequency amplifiers of French origin were Irkutsk (4,600 km. or 2,880 miles), Tschita (4,700 km. or 2,940 miles) and, using a simple detector receiver, Obdorsk (200 km. or 125 miles). This speech was obtained with good intensity in Christiania and Berlin. In the later case, Dr. A. Esau received the radio telephone messages from Moscow on a small loop antenna at Geltow. Since August, 1921, the inventor has perfected a new circuit for radio tele-

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phone modulation which has been described in number 10 of the journal "Radio Telegraphy and Telephony." This circuit can be used in any desired arrangement where vacuum tubes serve as modulators. It permits any desired increase of sensitiveness of the modulator, gives large outputs, and is very stable against disturbances. In this modulator circuit a microphone is connected thru a transformer to the grid circuit of a simple receiving tube. Thus the variations of potential on the grid of a second tube never exceed a certain value even for the largest fluctuations in potential of the grid of the first tube, and even if such large fluctuations result from small resistance changes in the microphone. In the autumn of 1922, the first Russian broadcasting station was established at Moscow at the Central Radio Telegraphic Station. This station was built on the Bontsch-Bruewitsch system, and has an antenna 150 m. (490 feet), antenna resistance 5.5 ohms, antenna power 5.5 kilowatts, and a range of 2,000 km. (1,250 miles).

A further considerable contribution to the field of vacuum tube technique was a radio-frequency cathode tube oscillograph produced by Professor A. A. Tschernischoff and Miss J. K. Schmidt. In their oscillograph, as with the Braun tube, cathode rays are used which are influenced by electric and magnetic fields. The difference between the Braun tube and their oscillograph is that in the Braun tube the cathode rays fall on a fluorescent surface, whereas in their arrangement they fall directly on a photographic plate in their path, thus acting on the sensitive film. For clear pictures of currents having a frequency of approximately 1,000,000 oscillations per second, voltages of 60,000 are required, which make it necessary to have a very high vacuum in the oscillograph. This has been obtained thru the use of three Langmuir pumps in parallel. In connection with this oscillograph, very high constant voltages are obtained by vacuum connected as kenotrons.

Mr. L. S. Termen has produced a musical instrument utilizing vacuum tubes which produce tones of desired pitch by utilizing the difference frequencies arising from two systems of definitely chosen pitch. Using this instrument, the discoverer has given highly successful concerts in Moscow and Petrograd. Engineer Guroff, of the Petrograd radio shop of the Naval Supply Service, has produced a musical instrument of similar type. Messrs. S. N. Rjewkin and B. A. Wredenski, of the Military Radio Laboratories, have investigated the phenomena of interrupted production of oscillations, and have produced a tube oscillator, built

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according to a method which the first of them had applied at the beginning of 1920. The method involves the insertion of a condenser in the grid circuit with a high resistance in parallel. Satisfactory regularity of the oscillations was observed, which were produced in separate groups. Between these groups there were shorter or longer pauses. This apparatus has been applied to measurements of capacities and high resistances, to wave meters for radio stations, and to the investigation of other physical phenomena, such as photo-electric effects, in the radio laboratories of the National Industrial Trust. Mr. A. A. Grigoriewa, engineer, has carried on a lengthy research on tube oscillations by self-excitation and on amplifiers using double grid tubes. Messrs. S. N. Rjewkin, N. N. Lutzenko, and B. A. Wredenski worked out a method of feeding the antenna, the plate, and filament circuits of cathode tubes with three-phase current, at the military radio engineering laboratories. In this system the transmitting tube acts also as a rectifier for high voltages. Mr. A. L. Mintz has worked out a new type of tube electrometer (voltmeter) for wire and radio telephony measurements.

In view of the increased use of cathode tubes of large output, it has become necessary to produce very high voltage rectifiers with correspondingly large outputs. This problem was solved in two ways. Professor W. P. Wologdin worked out a good construction of a very satisfactorily operative mercury arc rectifier. In the fall of 1919 at the radio laboratory at Nijni-Novrogod, Professor M. A. Bontsch-Bruewitsch produced a kenotron rectifier for direct current at voltages from 6,000 to 15,000 and up to 0.5 ampere or more.

4. In the construction of radio frequency alternators, the following progress has been made in Russia. A radio frequency alternator was produced by Professor W. P. Wologdin, and is of the uni-polar type, as are, for example, those of Alexanderson, Count von Arco, and others. The first model was produced by Professor Wologdin in 1912. The rotor of his machine consists of a number of sheets of equal resistance, and the stator is water-cooled. A considerable number of small machines have been built according to his plans; and these were followed by an alternator giving 50 kilowatts output, which gave good results in May, 1922. A 150-kilowatt alternator is in construction in his laboratory at this time, and the calculations for a 500-kilowatt machine have been completed in the designing division. It is noteworthy that the designer has been able to secure the necessary iron for the radio frequency alternator, with a thickness of

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... the Ural steel works. Machines ... various Russian high-power ...

... operation of the radio frequency alternators ... I. Eisenstein involves the utilization of the ... production of marked distortion of the ... generated voltage. Furthermore, when in a ... there exist several non-sinusoidal electromotive ... displaced from each other by 120 degrees ordi... system, all components with the exception of ... harmonic disappear. Using a special stator winding, ... can be multiplied 1.5 times. This permits of an alternator which produces the desired frequency for antenna ... at comparatively low speed.

Professor M. W. Schuleikin has produced a type of static frequency converter which he called a "harmonic resonance transformer" and such a transformer was built in the radio shops of the Naval Supply Service and tried out in practice. Professor Wologdin has described the construction of a static frequency transformer which in its simple form consists of two inductances in series, one of constant value and one of variable value, with a capacity in parallel with them.

The Poulsen arc converter has been widely used in Russia during the last four years for radio telegraphy. The Moscow "Feeble Current Trust," "Glaw-Elektro" has built a large number of such converters, under the engineering direction of Mr. Eisenstein. It should be stated that the chief constructional features of this type are almost the same as in the arcs which were received in Russia in 1917 from foreign factories. In 1919 a high power station was established in Moscow (Shabolovka) using a Poulsen arc of 100 kilowatts power in its primary circuit, which worked with the high power stations in Rome, England, and various other points.

The antenna is supported by two wooden masts which consists of four main beams, and are 150 meters (490 feet) in height. For a still larger trans-Atlantic station, not far from Moscow, there will be used wooden masts consisting of six poles, each 200 meters (645 feet) in height. The third mast of the Shabolovka Station is a metal lattice work tower 150 meters (490 feet) high, and built to be self-supporting in accordance with a very original design of Mr. Schustow, a Russian engineer.

Professor A. A. Tschernischoff worked out a new type of arc converter with a device for automatic regulation and which also

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permits of external adjustment of the arc. In the radio division of the National Experimental Electrical Engineering Institute, Mr. S. J. Turligin, engineer, has designed and constructed a model of a converter working in a steam and gas jet. He has also built the magnetic circuits out of iron dust and obtained good results.

6. In addition to ordinary open antennas, coil antennas have been widely used in Russia. In December, 1914, they were demonstrated by Mr. Eisenstein and were also used for special receiving arrangements by the author in the spring of 1915. The latter arrangements were used in Russia until 1921, but only for uni-directional reception. In December, 1920, they were used for practical communication at the central receiving station of Lubertzy, near Moscow. The antennas at this central receiving station are arranged in accordance with the author's methods for a number of duplex receptions. As was shown by the first trials, there is no disturbance of reception when the large transmitters at Moscow (Hodijnka and Shabolovka) are operating at full power. Experiments at this station in July, 1921, have shown that, with a mast 60 meters (200 feet) high, good reception could be carried on simultaneously from Paris, England, Nauen, Rome, and Taschkent, and that the operation of the high-power transmitter 20 to 25 kilometers (13 to 16 miles) away caused no marked disturbance. As a result, the traffic-carrying capacity of the principal radio telegraph stations of Moscow was increased six to seven times (because of the simultaneous reception of five messages while both of the high power stations were operating at the same time). In addition to increasing the amount of traffic which could be handled, this method of the author also lead to a great improvement in reception because of the reduction of atmospheric disturbances. In all the tests at this radio station on July 2, 1921, reception was entirely possible at a time when the receiving station 15 kilometers (9 miles) away, and using an ordinary open antenna on a mast 120 meters (400 feet) high, had been shut down for an hour because of a thunder storm. In the log of the latter station it was noted by the operators that they had observed heavy atmospheric disturbances, which, however, had not been noticed at Lubertzy.

Professor A. A. Petrowski has developed a triple sighting system for locating mobile radio stations using a number of loop receivers. This system can also be employed for the location of aircraft during flight.

Professor M. W. Schuleikin and A. L. Mintz have produced

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a calculating device which, designed according to Professor Schuleikin's ideas, facilitates the calculation of all the antenna constants. Thus, by two settings of the calculator, there can be obtained with sufficient accuracy for antennas of any common form, the values of the effective height, effective resistance, and values of inductance and capacity which must be connected into the antenna to tune it to any wave length.

A valuable contribution was made to the design of transmitting antennas in December, 1921, by Professor M. W. Schuleikin and J. G. Kliatzkin. They have improved Alexanderson's antenna system. Using a single mast, there is obtained theoretically the same or even greater range than with the Alexanderson system employing a number of masts. It is hoped that these theoretical conclusions will be speedily tried out experimentally.

The author and Mr. J. F. Plebanski applied in July, 1918, for a patent on a certain type of directional transmitter using a closed antenna system. Tests in the fall of the same year showed that radio telegrams from Ribinski to Sergiew-Posad, 200 kilometers (125 miles) from Moscow could be received there, while these signals could not be received at the station at Jaroslawl, 80 kilometers (50 miles) from Ribinski.

Engineer K. S. Tschetirkin proposed in March, 1919, to construct an operating radio central. According to the ideas of the author, the transmitting keys and the telephone receivers were to be placed in the central operating room, where, with the help of amplifiers and connecting wires, the transmitters could be controlled and the receiving signals recorded. Such arrangements have great advantages in the concentration of the entire activities of various transmitting and receiving stations with resulting increase in traffic handled. Tests at the station at Lubertzy have shown that the signals can be carried with very slight loss in readibility of 25 kilometers (16 miles) from the station to the Hotel Metropol in Moscow, where operators write down the messages.

7. Messrs. A. W. Dikareff and A. T. Ugloff in Kasan have worked out various new types of six-step amplifiers and external heterodyne oscillators, and have undertaken the manufacture of this apparatus on a large scale. Their equipment has been used widely in the Russian radio stations. In January, 1920, Mr. Ugloff used a multi-step amplifier for the amplification of speech drawn from wire lines. Such a loud-speaking telephone system has been used with great success in various parts of Mos-

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cow for propaganda purposes. Engineer R. W. Lwowitsch in the radio factory at Odessa has produced a direct indicating wave meter, with constant capacity and variable inductance of the variometer type and various other pieces of apparatus. Mr. Mintz has developed a method for receiving on open transmitting antennas as an emergency proposition. The engineers at the National Experimental Electro-technical Institute at Moscow have constructed an apparatus conceived by the author for measuring the decrement of received electromagnetic waves. This has been produced in two forms, the first of which uses a double coil antenna without any telephone shunts, and the second uses a simple coil antenna with variable shunts across the telephones.

Professor Petrowski and W. F. Mitkewitsch and Messrs P. P. Schilowski and O. A. Pawlinow have devised a form of tone signal radio station, the tone of which is definitely fixed by resonance to a low frequency, and the receiving system of which is based on a new optical arrangement. The same investigators have indicated a number of possibilities in the application of this system. Mr. S. J. Trojanski has carried on researches relative to the resistance of antennas and receivers as well as measurements on the magnetic fields in Poulsen arcs. His work has been practically applied in the design calculations of large Poulsen arc transmitters. Engineer N. N. Ziklinski has produced an apparatus for capacity measurements. The novelty to this apparatus consists in the use of two branches which enable the balancing of the entire system by the use of portions of a normal double condenser of variable capacity which is connected in both branches. Mr. A. F. Schorin had given methods of constructing special radio apparatus for the determination of geographical location using electromagnetic waves as early as 1918. The circuits are enclosed in a small cabinet which contains a receiver, amplifier, relay, and a chronograph with three pens which is driven by a small electric motor. Using Mr. Schorin's apparatus, the time signals from the radio station at Nauen were recorded, and by employing further amplification the time signals of the other large West European and Russian radio stations were also recorded.

In the field of high speed telegraphy, an invention made by Mr. A. F. Schorin at the end of 1917 has found wide application in Russia. At that time the German press messages from the station at Nauen were recorded on an ordinary Morse inker in the General Staff Headquarters in Petrograd, 30 kilometers (19

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miles) from the receiving station where the signals has been received.

At the beginning of 1919, Mr. A. F. Schorin undertook some researches between the stations at Detskoe Selo and Moscow. Signals from Nauen and Paris had been recorded in Moscow at fairly high speeds with Wheatstone recorders. Similar investigations were carried out, using Hughes apparatus. By the end of 1921, the inventor had worked out all details of a process which was suitable for use with the apparatus of Hughes, Wheatstone, Beaudot, and Siemens. Successful tests of high-speed operation were carried on between Moscow and Nijni-Novgorod in 1922.

Mr. W. N. Tejch presented a paper in 1919 before a meeting of the Russian Institute of Radio Engineers relative to the employment of small output relays for wire telephony and telegraphy. Mr. A. T. Ugloff employed vacuum tubes for the amplification of wire line telephone signals at the Military Radio Depot in Kasan, and also carried out multiplex telephony along iron wires over distances up to 600 kilometers (375 miles). Since the end of 1920 much work has been done in Russia in multiplex telephony on wires, using vacuum tubes. As is well known, the methods used involve the transmission of electromagnetic waves along the conductors. In this way it becomes possible to send several conversations over one wire. In the recent researches in 1921 in the Moscow Radio Laboratory of the Feeble-Current Organization ("Trust"), Messrs. P. W. Schmakow and G. A. Kuprianow carried out simultaneous conversations on a two-channel artificial cable circuit which was the equivalent of 250 kilometers (156 miles) of open wire, having a diameter of 4 millimeters (0.16 inch). Thus six conversations were transmitted at radio frequency and two at audio frequency. To prevent inductive disturbances, several electrical filters were used which transmitted frequencies up to 4,500 cycles without disturbing speech. Professor W. J. Romanow is working in the same field employing, however, only audio frequencies for the simultaneous transmission of several conversations. Professor Tschernischoff, W. D. Teikowjen, and Professor W. J. Kowalenkoff have developed methods for multiplex telephony along the high tension lines of the Moscow power plants, for example, for connecting the newly erected power plants at Schatursk and Moscow over the high tension lines.

Professor W. J. Kowalenkoff has also carefully worked out with much inventive skill a number of methods of using vacuum tubes on wire lines, in particular in connection with telephony. Mr.

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A. J. Kowalenkoff built a successfully operated radio telephone set for airplanes in flight in 1921. The first tube sets for this apparatus were constructed and tested by Mr. L. J. Sapelkoff in the Odessa Aerodrome in 1917.

8. In the field of radio television, various plans have been tried out in Russia but without practical success in any case. Mr. A. M. Kokurin, a student at the Technical High School in Moscow, applied in 1920 for a patent for the radio transmission of photographs. This inventor utilizes two antennas at his transmitting station, one of which sends the synchronizing signals while the other sends the actual pictures. Synchronization of the luminous points at the transmitting and receiving stations is obtained thru a successive shifting mechanism which is connected to the two antennas. Synchronization is carried out at a different wave length from the picture transmission. Other experiments in radio television have been carried out by Mr. L. S. Termen and Professor Kowalenkoff in Petrograd and Professor Bontsch-Bruewitsch in the laboratory at Nijni-Novgorod.

Mr. G. A. Solotowski, engineer, made public in 1921 all the details of a method for guiding ships thru narrow channels by means of submerged cables carrying electric currents. His methods were to send alternating currents thru a cable on the bottom of a channel and to provide the ship with a loop direction finder.

In the above brief description, it has been attempted to show the work which the Russian radio engineers have been carrying on during the last four years. Many of these investigations have been published in the journals "Radio Telegraphy and Telephony" and "Radio Engineering," and have thus become widely known in Russia. The latter periodical was succeeded in 1921 by the journal "Communication Engineering." The fact that since 1917 there have uninterruptedly appeared in Russia two periodicals in the field of radio engineering, one of scientific nature and one of popular type, and this during a time when all other technical periodicals suspended publication, is an indication of the great interest which the field of radio communication has excited in Russia. The organization and conduct of these journals, published in Nijni-Novgorod, are under the direction of Professor W. K. Lebedinski. It is owing to his vigorous work and conscientiousness, as well as his interest in the entire field, that during the last five difficult years in which Russian scientists have been completely isolated from the remainder of the world, there has ap-

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peared an important journal containing information of value to all the Russian radio engineers.

Valerian Bashenoff,
Gegarinsky perenlok 23, lodg. 28,
Moscow, Russia.

SUMMARY: The organization of the radio engineers of Russia and the relationship of the Institute of Russian Radio Engineers to other scientific organizations is described. The work of the Russian engineers since 1917 in a number of fields is summarized, with particular reference to vacuum tube amplifiers, low and high power transmitting tubes, portable stations, oscillograph measurements, radio frequency alternators and frequency multipliers, high power Poulsen arcs, directional reception, radio direction finding, radio centralized operation, broadcasting, precision measurements, high speed telegraphy, multiplex telephony along wires (guided radio), and pilot cables.

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SIGNAL-TO-STATIC-INTERFERENCE RATIO IN RADIO TELEPHONY*

By

John R. Carson

(Department of Development and Research, American Telephone and Telegraph Company, New York)

A criterion of fundamental importance in radio transmission is the ratio of the energy levels of the signal and of interference. The object of this note is to discuss the signal-to-*static*-interference[1] ratio in two systems of radio transmission described in a recent issue of these Proceedings.[2] The first system is known as single side-band transmission and is characterized by the transmission of only one side-band, the other side-band and the unmodulated carrier being suppressed. In the second system, both side-bands are transmitted, either with or without the carrier; both cases will be discussed.

In the propositions stated and discussed below, comparison is made on the basis of equal total energy transmitted or radiated from the sending stations.

I. *The signal-to-static-interference ratio in double side-band transmission with carrier suppression is equal to that in single side-band transmission, if and only if, in the double side-band system* (1) *over-all transmission is effected without appreciable phase distortion of the component frequencies, and* (2) *a local demodulating carrier or homodyne wave is provided at the receiving station which is exactly synchronous as regards both phase and frequency with the original carrier. Neither of these requirements is imposed on the single-side-band system.*

Both the requirements imposed on double side-band transmission in the foregoing proposition are necessitated by the fact that the equality of ratio presupposes that the two side-bands,

* Received by the Editor, May 4, 1923.

[1] The word *static* is used in a generic sense to cover random and irregular interference, such as atmospherics, as distinguished from the interference from another station.

[2] "Relations of Carrier and Side Bands in Radio Transmission," R. V. L. Hartley, Proceedings of The Institute of Radio Engineers, February, 1923. This paper should be consulted for a description of the systems of transmission dealt with in the present paper.

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after demodulation, come into exact phase. Under these circumstances the low frequency energy in double side-band transmission is twice that in single side-band transmission on the basis of the same transmitted energy. The mean interference energy, however, in the former system is twice that in the latter owing to the fact that the receiving system must receive a frequency band of double width.[3] Consequently the ratio is the same in the two cases.

The foregoing statement may be explained as follows. In the *radio frequency* receiving circuits, the signal energy is the same in the two systems of transmission. The interference energy, however, in double side-band transmission is twice that in single side-band transmission on account of the necessity of receiving a frequency band of double width in the former case. Consequently the possibility of obtaining equality of signal-to-interference ratio in the *audio frequency* circuits depends on *demodulating the radio-frequency signal in double side-band transmission with double efficiency* as compared with the interference. At first glance this might seem impossible; however, an examination of the problem shows that this can be accomplished provided the corresponding frequencies in the two-side-bands and the local and original carrier are so related in phase that the corresponding frequencies coalesce into a single frequency of double amplitude in the audio frequency side of the demodulator. This result, however, depends strictly on the requirements stated in proposition I. With phase or frequency fluctuation of the local carrier, the signal and interference are demodulated, on the average, with the same efficiency, giving a signal-to-interference ratio in double side-band transmission just ½ that of single side-band transmission.[4]

A brief consideration, however, will serve to show that the requirements imposed on double side-band transmission with carrier suppression for equality of signal-to-interference ratio are unrealizable in present-day practice and that consequently the inferences to be drawn from the preceding proposition as regards the possibilities of double side-band transmission are erroneous in their practical implications. As regards the first requirement,

[3] This statement can be established in a very general way without any assumptions regarding the impulsive character of static. A theoretical investigation of the problem will be published shortly.

[4] To guard against possible misunderstanding on the part of the reader, it should be clearly understood that the requirements stated above have to do with energy relations. It is not implied that any such severe requirements are imposed on double side-band transmission in order to have satisfactory transmission of signal.

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over-all transmission without appreciable phase distortion, no data are at hand to estimate the magnitude of this effect. Some rough calculations of wave transmission over sea water make it appear probable that the phase distortion would be small. On the other hand, it would seem probable that the over-all phase distortion, including that occurring in the terminal apparatus might be appreciable in long distance transmission. However, it is theoretically possible to introduce phase-correcting circuits at the receiving station, so that the first requirement, theoretically at least, can be satisfied.

As regards the second requirement, phase and frequency synchronism of the demodulating carrier, the case is different. The only known means of securing this synchronism is by transmitting some of the original carrier.[5] This, however, requires that some of the total transmitted power, in the case of double side-band transmission be assigned to the unmodulated carrier. This is not necessary in single side-band telephone transmission where, as discussed in the Hartley paper, phase distortion introduces no loss in signal energy and inappreciable loss in quality. In fact, an asynchronous homodyne can be employed.[6]

In view of these considerations the following propositions, rather than proposition I, correctly represent the actual possibilities of double vs. single side-band transmission.

II. *The signal-to-interference ratio in double side-band transmission with carrier suppressed is one-half the corresponding ratio in single side-band transmission, when account is taken of the phase and frequency variations from synchronism of the local carrier or homodyne wave.*

III, *The signal-to-interference ratio in double side-band transmission with carrier transmitted is* $1/(1+c)$ *times the corresponding ratio in single side-band transmission, where* c *is the ratio of the unmodulated carrier energy to the side-band energy in the former system.*

In the case considered in proposition II, account is taken of the fact that the local demodulating carrier or homodyne is inevitably subject to asynchronous variations, that is, departures as regards phase or frequency from the original carrier. This produces on the average a reduction of demodulated signal energy

[5] Whether energy is transmitted at the original carrier frequency or at some other frequency from which the carrier is derivable is immaterial to the present argument. The essential point is that energy must be transmitted in addition to the energy of the side-bands.

[6] As stated by Hartley, the case is different in *telegraph* transmission. The conclusions of this paper, as indicated by its title, are limited to telephonic transmission.

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[illegible] exact phase and frequency synchron-
[illegible] loss of energy, it seems probable that
[illegible] is inferior in radio-telephony owing
[illegible] energy level as the local homodyne swings
[illegible] phase.

[illegible] in proposition III, where the required
[illegible] side-band transmission is secured by car-
[illegible] one of most practical importance. In prac-
[illegible] carrier should be fairly large compared with the
[illegible] conservative figure for c is 2, which gives a relative
[illegible] interference ratio of 3-to-1 in single versus double
[illegible] transmission. It seems probable that this figure is
[illegible] and that 4-to-1 would more correctly represent the
[illegible] actually obtaining in practice.

To summarize, in addition to the very important gain in economy of the frequency range, single side-band transmission enjoys the added advantage of a very substantial gain in the signal-to-static-interference ratio. It is interesting to note that this gain is made possible not only by the narrower transmission band required, but by the fact that it is possible to employ an asynchronous homodyne wave.

Department of Development and Research,
American Telephone and Telegraph Company,
May 1, 1923.

SUMMARY: Several general propositions are stated relative to the signal-to-static ratio, in single and double side band transmission, indicating a superiority in practice for the former system.

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VACUUM TUBES AS POWER OSCILLATORS*

PART I

By

D. C. Prince

(Research Laboratory, General Electric Company, Schenectady, New York).

Foreword

The following discussion is an attempt to reduce power oscillator design to an engineering basis comparable with that upon which the design of motors and transformers now rests. In doing so, explanations are offered for many of the auxiliary disturbing phenomena.

By their nature, electron and high frequency phenomena cannot be directly measured and observed, so that the auxiliary phenomena especially must be explained by setting up hypotheses and then trying experiments which would be expected to produce certain results if the hypotheses are correct. Since an indefinite number of other hypotheses might produce the same result, it must be frankly admitted that some of the points raised border on speculation. In publishing this paper, it is the author's hope that evidence in confirmation or rebuttal may be brought out with a view to removing the subject as far as possible from the realm of uncertainty.

An attempt has been made to treat subjects which have had little or no discussion in the past, rather than to cover all uses of vacuum tubes. With the exception of Chapter VI, the discussion is limited to free oscillating circuits. In Chapter VI the forced circuit is touched upon merely to show how the same general methods of analysis may be used to determine the effect of the driven circuit upon the efficiency and output. These phases are most important in the free oscillator and have not been exhaustively treated in discussions of the forced oscillator.

The tests upon which this paper is based were made by Mr. F. B. Vogdes and Mr. A. Schmidt, Jr. The paper in its final form was prepared by Mr. Vogdes and edited by Mr. E. W. Kellogg. I wish to thank these men for their able assistance.

*Received by the Editor, March 15, 1923.

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CONTENTS

CHAPTER I

An exact method is developed whereby the performance of a vacuum tube as an oscillation generator can be determined, together with the required voltages which must be impressed upon the different members to secure such results. Starting and blocking are discussed.

CHAPTER II

An approximate method is developed whereby the effect of varying factors, such as space charge, voltage, and so on, can be more readily determined than by the laborious exact method of Chapter I.

CHAPTER III

Based on the conditions required for the tube as developed in Chapter I, the design of a single tuned circuit is developed. Criteria are established for selecting the value of inductances and capacities thruout the circuit. Conditions for intermittent oscillation are discussed.

CHAPTER IV—*Chapters IV and V will appear in the August* PROCEEDINGS

The design of a partially tuned plate circuit is developed. The procedure is characteristic of the methods which may be used in a large variety of circuits which depend upon one inductance and capacity to establish the frequency, but which have other inductances and capacities coupled to the main circuit.

CHAPTER V

The operation of vacuum tubes in doubly periodic circuits is developed. The criterion for double periodicity is simply derived. Methods of controlling oscillations in doubly periodic circuits are suggested.

CHAPTER VI—*Chapters VI, VII, and the Appendix will appear in the October* PROCEEDINGS

The influence of the receiving circuit on the efficiency and output of a vacuum tube power amplifier is discussed.

CHAPTER VII

The methods of Chapter I are applied to circuits in which

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the plate voltages are not sinusoidal. It is shown that efficiencies and outputs may be considerably increased by circuit arrangements which give special wave form.

APPENDIX

A brief comparison is given showing the correspondence between theory and observation affecting emission, space charge, and amplification constant. The division of primary and secondary electrons between grid and plate is discussed.

CHAPTER I

VACUUM TUBES AS POWER OSCILLATORS

The purpose of this discussion is to develop the process of calculating the performance of a power oscillator from its characteristic curves. The first part will be restricted to sinusoidal wave forms found in simple circuits. The fundamental relations are as follows: Referring to Figure 1, let:

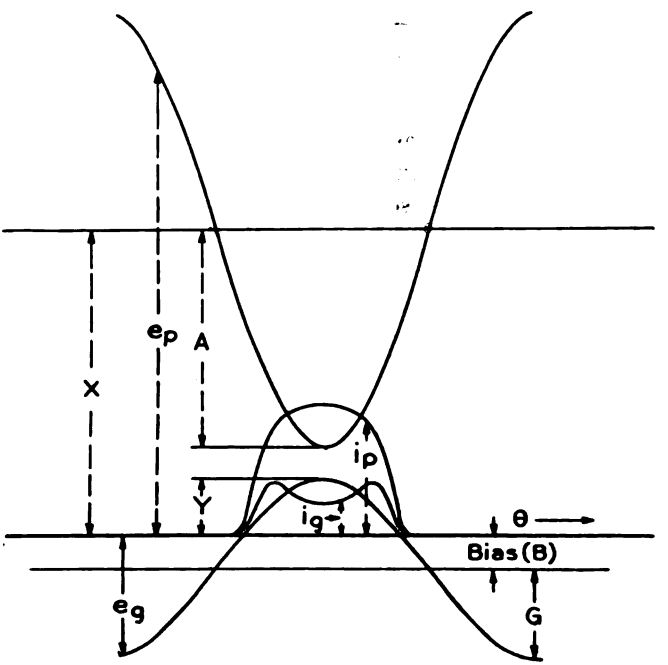

FIGURE 1—Potential and Current Relations for a Pliotron Oscillator

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X = Direct current impressed plate potential in relation to filament.

e_p = Instantaneous plate potential in relation to filament.

i_p = Instantaneous current to plate.

e_g = Instantaneous potential, grid to filament.

i_g = Instantaneous grid current.

Then

$X\,i_p$ = Instantaneous input to plate.

$e_p\,i_p$ = Instantaneous plate loss.

$e_g i_g$ = Instantaneous grid loss.

$$e_p\,i_p + e_g\,i_g = \text{Total instantaneous tube loss} \tag{1}$$

$$(X - e_p)\,i_p - e_g\,i_g = \text{Instantaneous net output} \tag{2}$$

$$\frac{(X - e_p)\,i_p - e_g\,i_g}{X\,i_p} = \text{Instantaneous efficiency} \tag{3}$$

The foregoing instantaneous values must be integrated over a complete cycle to secure average values:

$$\int_o^{2\pi} X\,i_p\,d\theta = \text{average input} \tag{4}$$

$$\int_o^{2\pi} (X - e_p)\,i_p - e_g\,i_g\,d\theta = \text{average output} \tag{5}$$

$$\frac{\displaystyle\int_o^{2\pi} (X - e_p)\,i_p - e_g\,i_g\,d\theta}{\displaystyle\int_o^{2\pi} X\,i_p\,d\theta} = \text{average efficiency} \tag{6}$$

The foregoing relations are quite independent of tube characteristics, frequencies, and wave shapes. Tube characteristics cannot readily be expressed by equations of the characteristic curves because they are divided into zones which follow different physical laws. For amplification purposes, operation is usually restricted to a small part of one zone where one law holds, but the amplitude of sustained oscillations is determined by the passage from one zone to an adjoining one. This will be clear by reference to an actual set of static characteristic curves. Figure 2 is such a set of curves taken from a General Electric Company one-kilowatt tube. Below 10 volts, the current is approximately proportional to the 5/2 power of the voltage. The exponent drops gradually to 3/2 above 10 volts, then becomes unity about 250 volts, and later becomes negative. However, by making use of the characteristic curves directly, integration may be accomplished by steps. That is, a series of points in the cycle may be selected, and inputs and outputs so obtained may be averaged over a cycle.

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No measurable lag exists in the movement of electrons, so that frequency is unimportant except as it affeets the circuits associated with the tube.

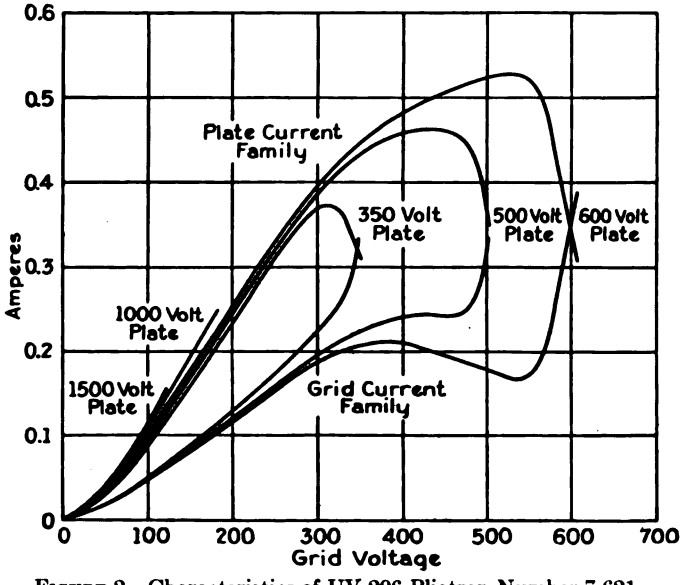

FIGURE 2—Characteristics of UV-206 Pliotron Number 7,621

In performing step by step integration, the five variables, X, e_p, e_g, i_p, i_g, must be determined. The procedure is as follows:

X is the direct impressed voltage for which the tube is designed—in this case 10,000.

e_p cannot be defined in general terms. In an oscillator of reasonably low losses, the induced voltages may be assumed sinusoidal with very slight error. The wave form is, therefore, known, but not the amplitude. Let "A" denote the amplitude. The sinusoidal term of e_p is superimposed upon the impressed direct potential.

e_g is induced by the same flux as e_p, and is, therefore, of the same shape. From equation (5), positive output is obtained by having e_p a minimum while i_p is maximum. That is, e_p and i_p are 180° out of phase. But i_p and e_g are in phase. (See characteristics, Figure 2), therefore e_p and e_g must be 180° out of phase. Amplitude and axis of e_g are unknown. Let "G" and "B" represent these values.

i_p and i_g are read directly from the characteristic, if e_p and e_g are known.

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The general three-element tube equation is

$$i = f\left(e_g + \frac{e_p}{\mu}\right) \tag{7}$$

from which it appears that

$$e_g = -\frac{e_p}{\mu} \text{ for } i_p = 0. \tag{8}$$

Let $$e_p = X - A \cos\theta \tag{9}$$

and $$e_g = -B + G \cos\theta \tag{10}$$

then if θ_1 = Angle at which $i_p = 0$

$$-B + G \cos\theta_1 = -\frac{X - A \cos\theta_1}{\mu} \tag{11}$$

For angles greater than θ_1 the inputs and outputs are both zero, so that integration need not be carried beyond this point. Equation (11) contains A, B, and G, which may be considered the independent variables.

Let "Y" be the distance which the grid swings above the zero axis.

Then $B = G - Y$ and (11) may be written

$$\frac{X - A \cos\theta_1}{\mu} = -Y + G(1 - \cos\theta_1) \tag{12}$$

Now $X - A$ is the minimum voltage between plate and filament and Y is the maximum positive grid potential. Inspection of the characteristics (Figure 2) shows that if $Y > 0.8\ (X\text{-}A)$, the condition is approached where i_p decreases and i_g increases. This represents a potential reduction both in output and efficiency so that operation should not be carried beyond this point. Another way of stating this proposition is that, when an oscillator is started, the oscillations continue to increase in amplitude until the circuit losses balance the output. This point has been estimated by inspection to occur when the maximum grid voltage is 80 per cent of the minimum plate voltage. That this assumption does not involve any great error may be seen from the following considerations. Referring to calculated point (Table II), an increase of 2 per cent in plate induced voltage would be 185 volts. The corresponding increase in grid volts would be 18. The resulting minimum plate and maximum grid voltages are then 565 and 618, respectively. For this condition the grid receives most of the emission current and the plate practically none (see characteristic, Figure 2). The output would, therefore, be greatly reduced and the tube would be unable to sustain the in-

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creased loss involved in the wider amplitude of oscillation. Since the output is reduced for an increase of less than 2 per cent in the alternating current plate voltage and is obviously reduced for any reduction in plate voltage, it appears that the assumed values are very near to the point of stable operation. A selection of A then determines Y and an added selection of θ_1 determines G. We have then two independent variables, A and θ_1, to which a series of values may be assigned and the performance of the tube investigated.

To facilitate this work the form shown in Table I has been prepared with the instructions for filling in each line. Table II is a sample calculation of one operating point using this form. Lines A to K inclusive are used only once for a given pair of values of maximum grid and minimum plate volts. Lines L to S must be filled in separately for each operating point.

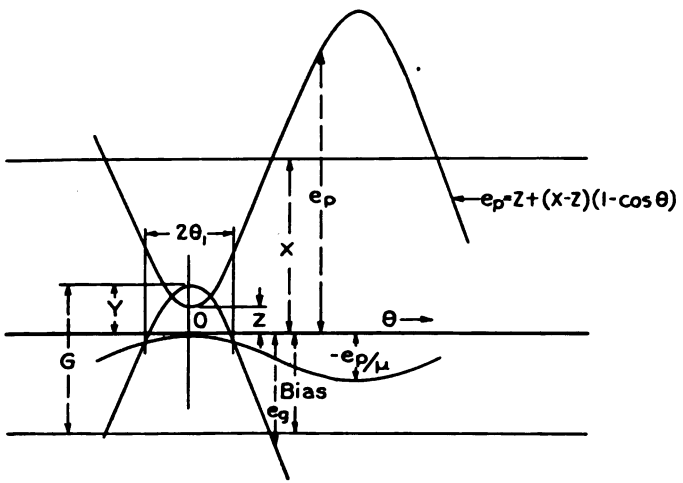

FIGURE 3

The nomenclature has reference to Figure 3. With the one-kilowatt tube for which characteristics are given, the plate and grid current families are so compact that they can be combined into one and extrapolated with reasonable accuracy. This was done in Figure 4, to permit calculation of points using minimum plate voltages as high as 1,000. The momentary tube losses represented by a plate potential of 1,000 and grid potential of 800 are so high that no static characteristic readings could be taken in that region. The ideal

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method of taking characteristics is with an oscillograph, since this permits momentary currents and voltages to be recorded without damage to the tube.

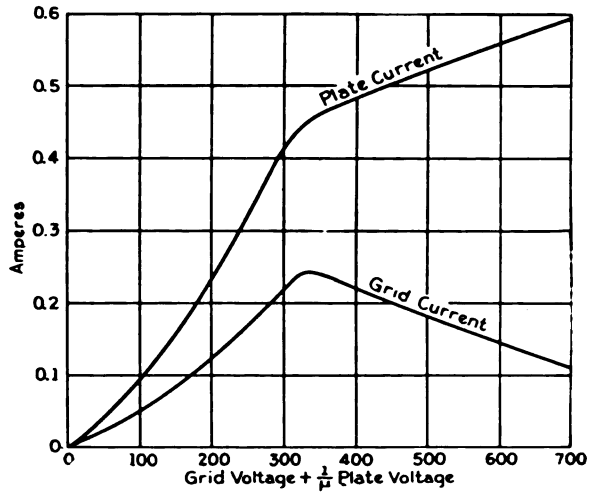

FIGURE 4—Extrapolated Characteristics of Pliotron UV-206, Number 7,621

Figure 5 shows the result of calculating points for three values of minimum plate potential with varying θ_1. Since θ_1 of itself is of no interest, the values have been plotted against output instead. The output of the tube is limited by heating of the plate which in this case may safely dissipate 350 watts. Outputs of 1,080, 1,195, and 1,215 may thus be obtained within the capacity of the tube by the adjustments indicated. It would appear that the efficiency curves and loss curves should cross at the same outputs. The reason that they do not is that grid leak bias losses are included in efficiency determinations, altho they do not contribute toward tube heating.

It is apparent that for still higher minimum plate voltage, the watts output at 350 watts loss would ultimately be less than that for 1,000 volts minimum plate. The optimum conditions for maximum output are, therefore, in this neighborhood, altho considerable latitude is permitted without loss of output. Since these values are not functions of frequency, they form the basis for the design of practically any oscillating circuit in which these tubes are operated at 10,000 volts.

The performance of other tubes or of the same tube at other supply voltages and filament currents are similarly obtained.

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It is apparent from Figure 5 that the adjustment which will give the greatest output is not necessarily best for a lesser output. An envelope can be drawn so as to include the points of minimum loss for any particular output. Such information can be plotted up and used as a basis for selecting the proper circuit constants for any set of conditions. This has been done in

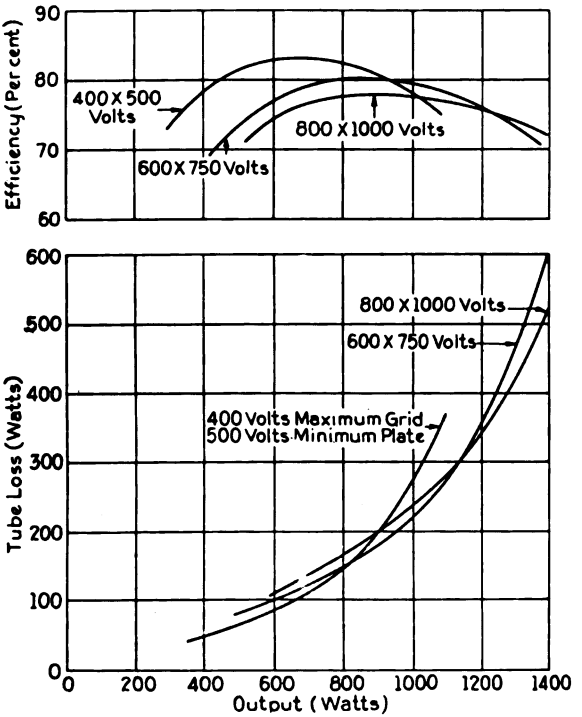

FIGURE 5—Calculated Efficiency and Loss in a UV-206 Tube at 10,000 Volts Direct Current

Figures 6 and 7. The corresponding loss-efficiency curves for 15,000 volts are shown in Figure 8. Having decided upon the desired power, the circuit constants may be taken from Figures 6 or 7, and the loss and efficiency from the other curves.

STARTING PROPERTIES

With a tube of known performance, it is not ordinarily necessary to make an investigation to determine whether oscillations will start automatically. In special cases, however, it may be desirable to verify this point. Suppose it is necessary to determine whether oscillations will be self-starting for the point

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calculated above. Immediately after closing the switch, the plate potential is the full direct impressed voltage or 10,000 volts. The grid is at zero. Figure 9 shows this portion of the characteristic. Any transient disturbance such as the closing of the switch will start a small circulating current in the oscillator circuit. This will induce voltages which will be divided between plate and grid in the fixed ratio determined by the connections to the oscillating circuit. For the point under consideration $\Delta e_g = -0.104\ \Delta e_p$.

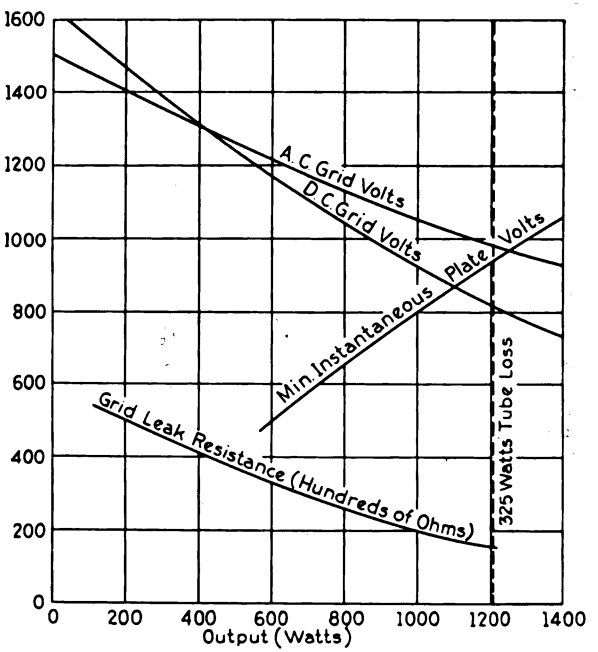

FIGURE 6—Calculated Optimum Operating Conditions for a UV-206 Tube at 10,000 Volts Driect Current

Values of plate current can be plotted against induced plate voltage maintaining the relation $\Delta e_g = -0.104\ \Delta e_p$. To do this a series of plate voltages are assumed such as 10,000, 9,900, 9,800, 9,700, etc. The difference between these values and 10,000 are equivalent to induced voltages in an oscillating circuit and the grid voltages are -0.104 times these values. Figure 10 represents the resultant derived characteristic. By drawing a second axis X' thru the current value at zero volts and referring currents to the new axis, any point on the curve represents volts and amperes, alternating current instantaneous output. Over a

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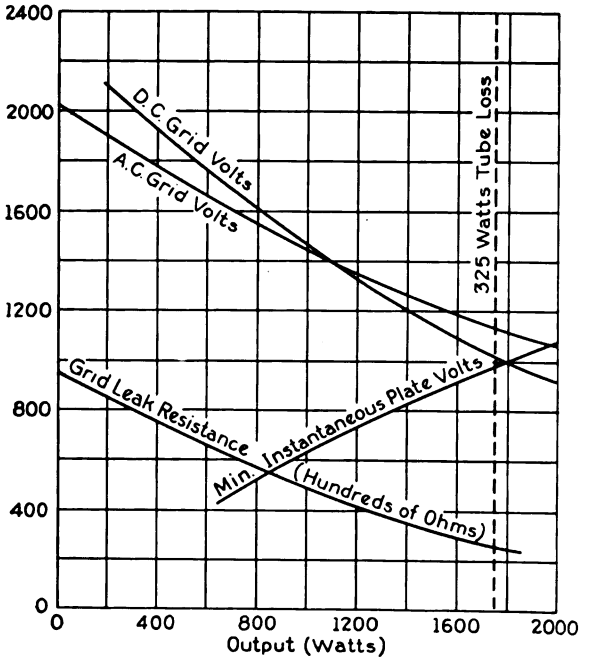

FIGURE 7—Calculated Optimum Operating Conditions for a UV-206 Tube at 15,000 Volts Direct Current

short distance from the origin the curve may be considered a straight line, the reciprocal of the slope of which is the ohmic resistance which would just use up the energy output of the tube. If the equivalent resistance of the circuit is greater than this amount, oscillations will start and increase until a stable point is reached. The energy consumed is $W_L = \frac{(\Delta e_p)^2}{r}$. If "$r$" is increased, less energy is consumed and the surplus is stored in the form of oscillating energy in the circuit until increased amplitude of oscillation fails to yield a sufficient increase in output to support the increase in losses. The equivalent resistance is the resistance of a multiple tuned circuit which is inversely proportional to the ohmic resistance in the parts of the circuit. In the case under investigation full load corresponds to a resistance of 35,800 ohms. The oscillations would be self-starting with 8,700 ohms, so that starting is certain. The range between 8,700 and 35,800 is a zone within which continuous operation will overheat the tube, and so is not useful, except that it represents a margin of safety as far as self-starting is concerned. For lower

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impressed voltage, this margin becomes progressively narrower until a point is reached where oscillations will not be self-starting, but will be maintained if once started. This point must be borne in mind when adjustments are being attempted at reduced voltages. A circuit in perfect adjustment will often fail to start at all on half voltage altho it will oscillate well if the full voltage is thrown on and then reduced.

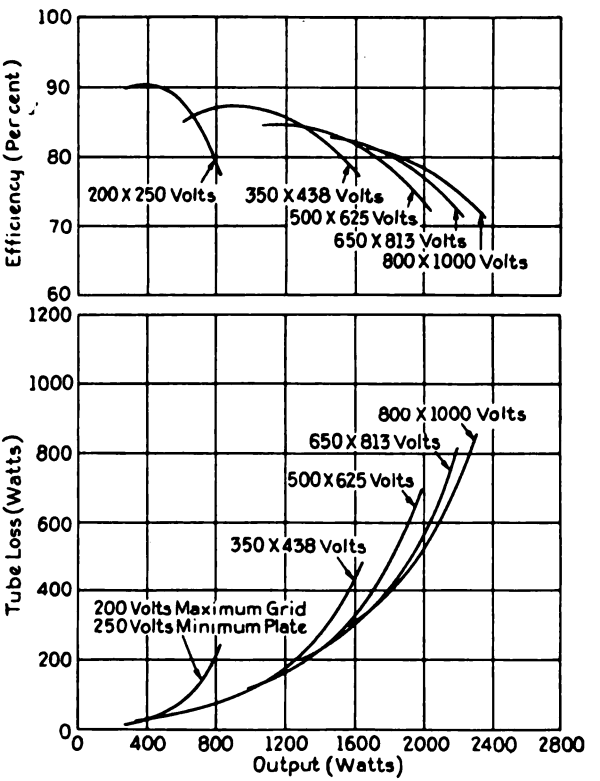

FIGURE 8—Calculated Efficiency and Loss in a UV-206 Tube at 15,000 Volts Direct Current

No conclusions can be drawn from Figure 10 as to the stable oscillations of the circuit at full amplitude. As soon as oscillations have commenced the grid begins to bias itself negatively, so that the axes of this graph are no longer maintained.

BLOCKING

Certain tubes, even tho well designed, are subject to a phenomenon technically known as blocking. The visible evidences

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of this phenomenon are cessation of oscillation accompanied by a sudden increase of plate current to a value larger than that which can be obtained with full voltage and zero potential on the grid. A high power tube is usually destroyed by blocking, since the energy dissipated in the heating of the plate is enormous.

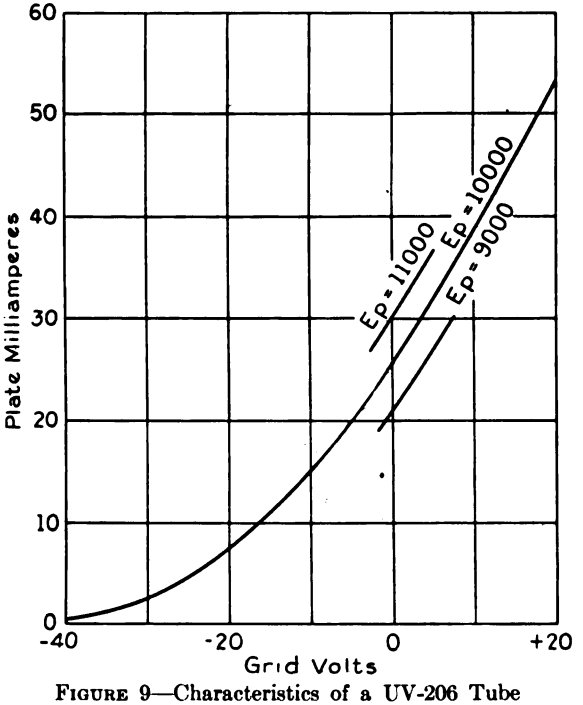

FIGURE 9—Characteristics of a UV-206 Tube

The General Electric Company's one-kilowatt tube, which has been used as an example, is practically immune from blocking, but the nature of the phenomenon can be studied by arbitrarily extrapolating the composite characteristic (Figure 4). Figure 11 could conceivably apply for a plate voltage of 2,000. After the grid voltage passes 1,000, the grid current reverses. If the average current is in the reverse direction, the drop in the grid leak is reversed so that the axis about which the grid swings is positive. Now since current flows from the grid terminal when positive voltage is applied to it, there is the equivalent of negative resistance of a value e_g/i_g between grid and filament, i_g being negative. If the grid leak have a value of say 18,000 ohms, the drop in the grid leak will be 1,250 volts for a current of

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−70 ma. and this drop will maintain the grid at 1,250 volts. A condition of equilibrium is established at "*A*," but it is unstable, since −80 ma. will give a drop of 1,440 volts across the resistance, which is sufficient to cause the flow of −130 ma. −130 ma. would give a resistance drop and hence the grid a potential of over 2,000 volts, but at this point the current would again reverse so that stability is established at "*B*." By drawing a tangent from the origin thru "*C*," the minimum resistance is found for which stable equilibrium can be established with the grid at a positive potential. For lesser values of biasing resistance, blocking cannot take place.

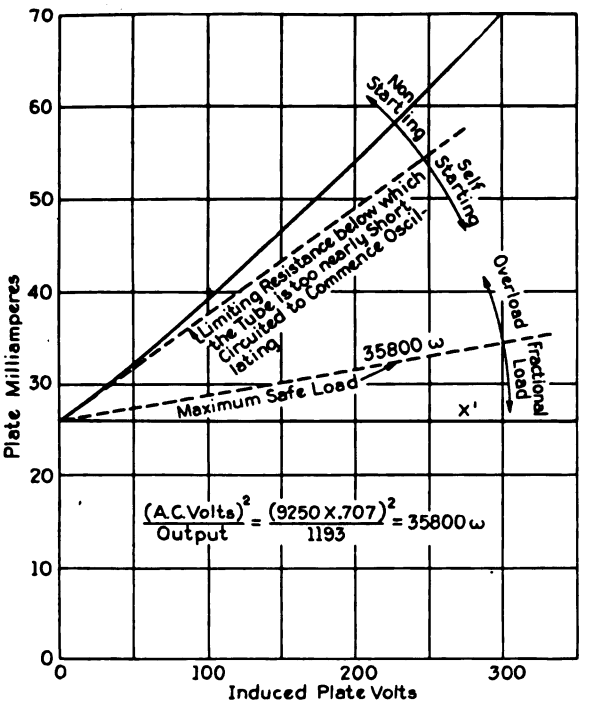

FIGURE 10—Oscillator Starting Characteristics at 10,000 Volts Direct Current

It will be noted that three simultaneous events are necessary to give blocking: the minimum plate voltage must be high; the maximum grid voltage must be high; and the grid leak resistance must be high. this situation is obtained if the output of the oscillator is forced by decreasing the effective resistance of the plate circuit. This reduces the amplitude of os-

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cillation and increases the minimum plate potential. The operator, in trying to restore the oscillation amplitude, raises the grid excitation, which carries the grid beyond the potential at which grid cuorent begins to decrease. This reduces the average current, which, in turn, reduces the negative bias, allowing the grid to swing into a still more positive zone until blocking results.

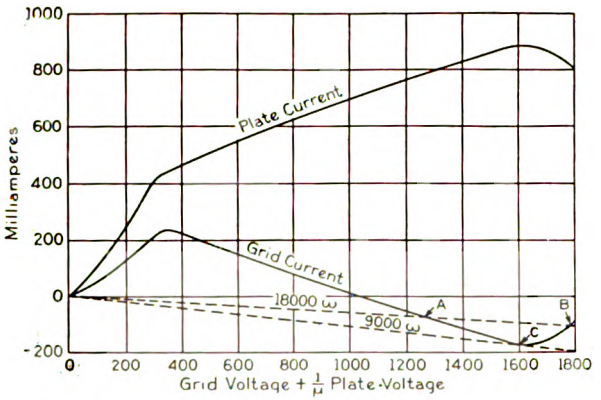

FIGURE 11—Characteristic Curve Showing Blocking Condition

By reasonable care in circuit design, blocking may be entirely avoided. Take, for instance, the point already calculated. The circuit adjustment was such that the full plate swing of 9,250 volts gave a corresponding grid swing of 960 volts. Since the plate supply is 10,000 volts, the minimum plate voltage is 750. Thus, before the grid approaches a potential at which its current becomes negative, the plate potential is too low for blocking to take place.

CHAPTER II

APPROXIMATE THEORETICAL PLIOTRON PERFORMANCE WITH SINE WAVES OF PLATE AND GRID POTENTIAL

For some qualitative analysis, vacuum tube oscillator performance may be approximated by substituting a portion of a sine wave for the actual current wave obtained in the foregoing exact method. Such a wave may be integrated mathematically instead of by the laborious step-by-step method. Referring to Figure 12:

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Let E = Direct potential impressed upon the circuit.

e_p = Filament to plate potential.

a = Fraction of total potential not consumed by space charge.

i_p = Plate current.

I = Maximum value of plate current.

c = Such a value that $(1+c)\,I$ gives the maximum plate current referred to the axis about which it is sinusoidal.

θ_1 and θ_2 = Points at which plate current curve intercepts the zero axis.

$e_p = E\,(1 - a\,sin\,\theta) = E\,f_1\,\theta.$

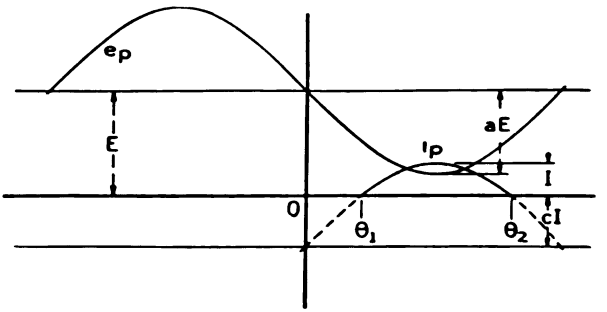

FIGURE 12

Since the oscillating circuit is highly tuned, it responds only to impulses of fundamental frequency and hence the voltage is a pure sine wave. For full load operation, maximum current must flow when the tube drop is a minimum, so that the plate potential does not swing lower than $(1-a)\,E$, which corresponds to the space charge loss.

$$i_p = I\Big(-c + (1+c)\,sin\,\theta\Big) = I\,f_2\,\theta$$

The fundamental law is, of course,

$$i_p = K\left(E_g + \frac{1}{\mu}E_p\right)^{3,2}$$

but with the grid potential 180° out of phase with plate potential, the actual resultant expression approaches closely $i_p = K\,E_g$. If we wish $i_p = K'\,sin\,\theta + K''$, the expression for E_g may be modified so that this result will be obtained. With this approximation, it is not necessary to use step-by-step integration.

The input of the oscillator is given by the expression

$$W = E\,i_p = E\,I\,\Big(-c + (1+c)\,sin\,\theta\Big)$$
$$= E\,I\,f_2\theta \qquad (1)$$

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The tube loss is equal to the instantaneous product of current and drop across the tube, that is,

$$\text{Loss} = E\,I\,(1-a\sin\theta)\left(-c+(1+c\sin\theta)\right)$$

$$= E\,I\,f_1\theta\,f_2\theta \tag{2}$$

$$\text{Output} = (1)-(2) = E\,I\,f_2\theta\,(1-f_1\theta) \tag{3}$$

$$\text{Efficiency} = (3)/(1) = \frac{E\,I\,f_2\theta\,(1-f_1\theta)}{E\,I\,f_2\theta}$$

$$= 1-f_1\theta = a\sin\theta \tag{4}$$

To determine average efficiency the instantaneous efficiency must be weighted in proportion to the input.

$$\text{Average Efficiency} = \frac{\int_{\theta_1}^{\theta_2} E\,I\,f_2\theta\,(a\sin\theta)\,d\theta}{\int_{\theta_1}^{\theta_2} E\,I\,f_2\theta\,d\theta} \tag{5}$$

$$= \frac{\int_{\theta_1}^{\theta_2} a\sin\theta\,[-c+(1+c)\sin\theta]\,d\theta}{\int_{\theta_1}^{\theta_2} [-c+(1+c)\sin\theta]\,d\theta} \tag{6}$$

$$= \frac{a\int_{\theta_1}^{\theta_2} [-c\sin\theta+(1+c)\sin^2\theta]\,d\theta}{\int_{\theta_1}^{\theta_2} [-c+(1+c)\sin\theta]\,d\theta} \tag{7}$$

$$= \frac{a\left[c\cos\theta+\frac{(1+c)}{2}\theta-\frac{(1+c)}{4}\sin 2\theta\right]_{\theta_1}^{\theta_2}}{\left[-c\theta-(1+c)\cos\theta\right]_{\theta_1}^{\theta_2}} \tag{8}$$

Since the thermionic valve has uni-directional conductivity, there can be no current reversal. The expression is, therefore, meaningless unless θ_1 and θ_2 are chosen to include that portion of the cycle during which current flows. During the remainder of the cycle there is neither input not output, so that integration between these limits gives the complete result.

With the origin as shown, the following relations between the limits and constants exist:

$$\frac{c}{1+c} = \sin\theta_1 \qquad \cos\theta_2 = -\cos\theta_1$$

$$\theta_2 = \pi-\theta_1 \qquad \sin 2\theta_2 = -\sin 2\theta_1$$

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The complete expression can then be written:

$$\text{Efficiency} = \frac{a\left[\frac{1+c}{2}(\pi - 2\theta_1) - 2c\cos\theta_1 + \frac{1+c}{2}\sin 2\theta_1\right]}{-c(\pi - 2\theta_1) + 2(1+c)\cos\theta_1} \quad (9)$$

The value "I" has been selected as a constant, because the maximum emission of any tube is a constant, depending upon filament rating. The expression for output (3) can, therefore, be evaluated to show the variation in output accompanying variations in efficiency. Equation (3) solved gives the numerator in equation (9) for $E\,I = 1$.

In Figure 13 efficiency and output as a percentage of the maximum are plotted for "a" = 1.

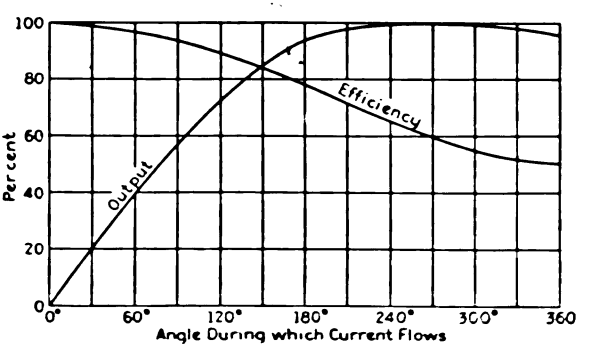

FIGURE 13—Theoretical Efficiency of Pliotron Oscillators. Variation with angle during which plate current flows, neglecting space charge and assuming current wave proportional, above cut-off value, to sine grid potential. Maximum plate current constant

In Figure 14, curves are plotted for various values of "a." showing efficiency, output, and loss for current flowing for different fractions of the cycle.

In order that conclusions may be drawn, the output and loss curves have been plotted to scales inversely proportional to $(1-a)$, taking the maximum output for $(1-a) = 5$ percent, as 200 for convenience. If the curves are considered as applying to one tube, the space charge in percent will be inversely proportional to the voltage applied, "I" remaining constant, therefore

$$\text{Output} = E\,I\,f_2\theta\,(1 - f_1\theta)$$

and where $E \propto \frac{1}{1-a}$

$$\text{Output} = \frac{K''I}{1-a} f_2\theta\,(1 - f_1\theta)$$

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The curves as plotted, therefore, represent the conditions encountered when impressed voltage is varied.

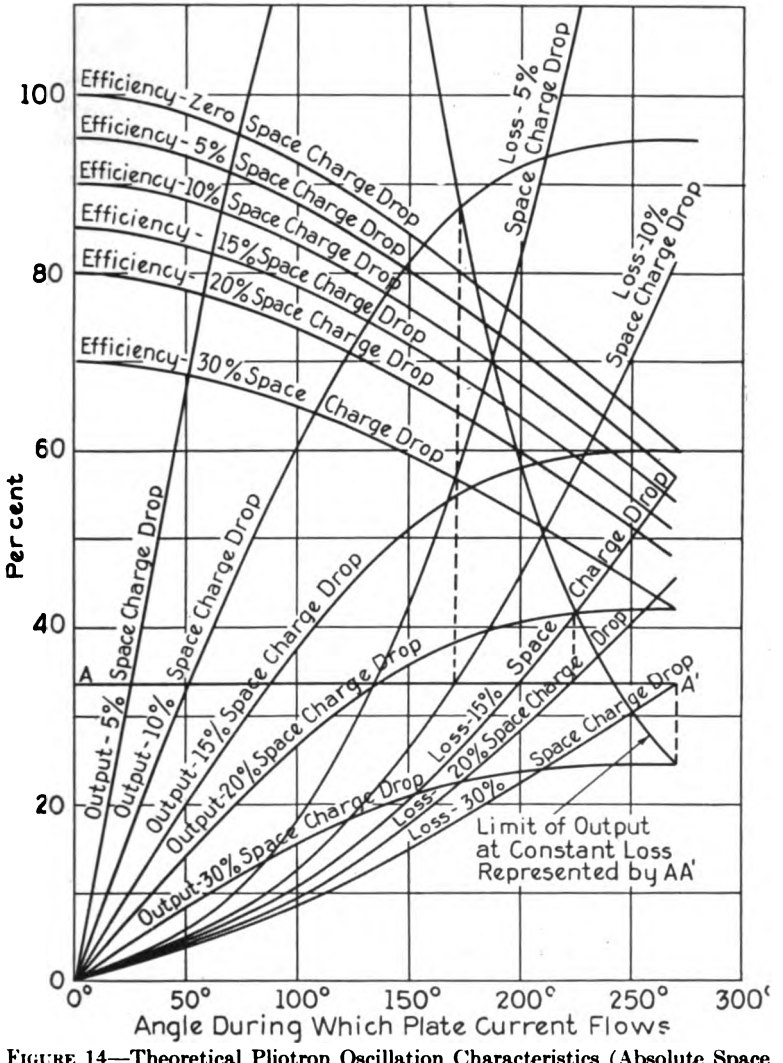

FIGURE 14—Theoretical Pliotron Oscillation Characteristics (Absolute Space Charge Constant, Impressed Voltage Variable)

Since the tube output is limited by heating, the effect of voltage variation on tube output can be deduced directly. Any line, say "AA'" is drawn, representing maximum dissipation for a given tube. The intersections of this line with the loss curves are the angles during which current can be passed at differents

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voltages. The same abscissas extended to the output curves determine the variation in output at constant heating.

Assuming 1,000 volts space charge drop, the variation of output with voltage is plotted in Figure 15. The scale of outputs is based on the maximum possible output of the tube on 20,000 volts, neglecting heating. It will be observed that the curve shows a slight tendency to saturate, but that output at constant heating is still increasing almost in proportion to voltage when space charge is reduced to 5 percent of the impressed voltage.

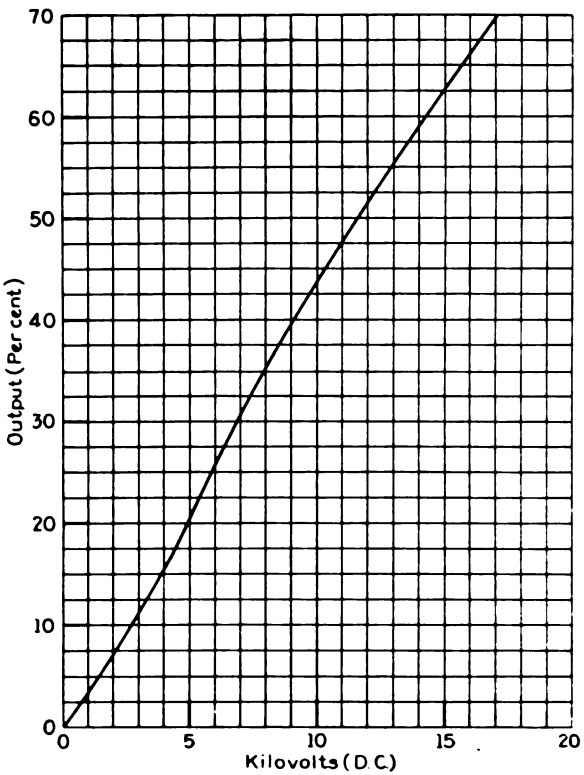

FIGURE 15—Theoretical Pliotron Characteristics. Variation of Output with voltage, maximum current and loss constant

For convenience in determining the currents indicated by a direct current meter in the plate circuit under the foregoing conditions, Figure 16 has been prepared. Curve "A" applies to currents of the form assumed in the foregoing calculations of oscillator efficiency, while curve "B" gives the corresponding

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figure for tubes operated as rectifiers without smoothing devices.

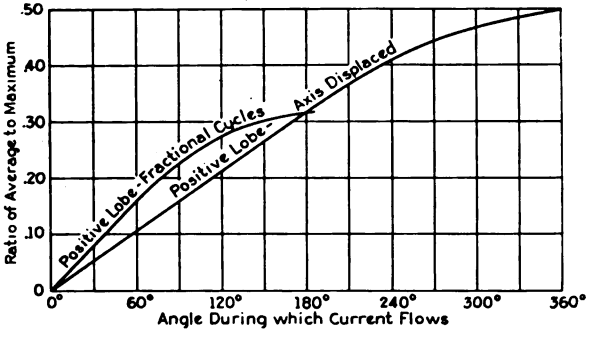

FIGURE 16—Ratio of Average to Maximum for Sine Waves

In order to obtain an idea of the grid swing required to secure various efficiencies where sinusoidal excitation is used, conditions have been assumed as shown in Figure 17. It has been assumed that, for oscillators, the grid potential will swing positive as the plate swings negative until the two approximately meet.

Let e_p = plate potential = $E\ (1-a\ cos\ \theta)$

e_g = grid potential = $E\ (-b+g\ cos\ \theta)$

E = direct potential impressed.

$1-a$ = ratio of space charge drop to E.

b = ratio of grid bias to E.

g = ratio of maximum grid swing to E.

d = ratio of current cut-off point to E.

$E\ d = \frac{e_p}{\mu}$ = grid potential necessary to reduce current to zero.

Since all values are expressed as ratios to E, the E will be assumed as unity in the following relations:

$1-a$ = mazimum plus grid swing

$b+1-a=g$.

$2\theta_1$ = angle during which current flows. The grid swings positive from the point where current begins to flow by a distance.

$$M=(1-a)+d_1=1-a+\frac{e_{p_1}}{\mu}$$

$$=1-a+\frac{1-a\ cos\ \theta_1}{\mu}$$

$$g\ cos\ \theta_1=g-M$$

$$\text{Or } g=\frac{\left[\frac{1+\mu}{\mu}-a\left(\frac{1}{\mu}cos\ \theta_1+1\right)\right]}{1-cos\ \theta_1}$$

$$b=g-(1-a)$$

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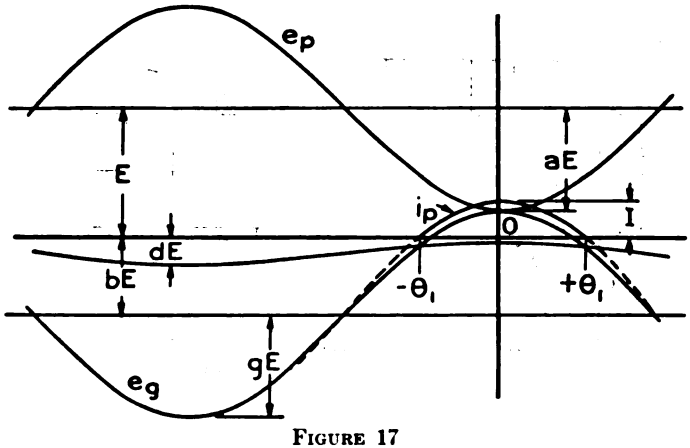

FIGURE 17

The curves in Figure 18 show variations in "g" with $2\theta_1$, the angle during which current flows, for $a = 0.95$ and $\mu = 10$ and $\mu = 100$. For small values of θ_1, "g" approaches infinity, so that if high efficiency is to be obtained with sine excitation, the potential, from grid to filament may be equal to, or even greater than those from plate to filament.

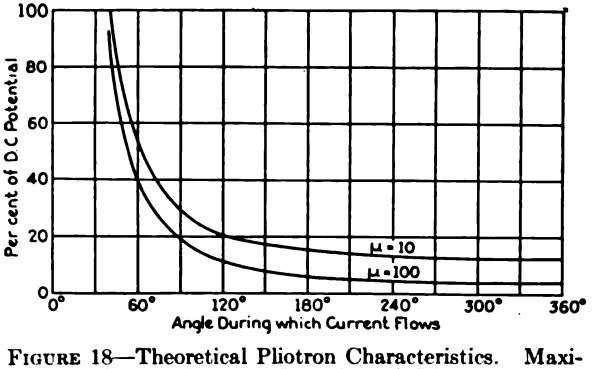

FIGURE 18—Theoretical Pliotron Characteristics. Maximum Grid Potential as a Function of Direct Potential Impressed on Plate. Grid Excitation Sinusoidal. Space Charge 5 percent. Maximum Plus Grid Potential equals Minimum Plate Potential

CHAPTER III

CIRCUIT DESIGN

The design of vacuum tube oscillator circuits hinges on two points:

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1. An oscillating circuit must be supplied in which there is sufficient energy stored to carry the circuit by its flywheel effect over those parts of the cycle during which the input to the circuit is not equal to the losses.
2. The voltages applied to the tube must be in amplitude and phase of proper value as determined in Chapter I.

Stored Energy

Consider a circuit having an inductance "L" and a capacity "C" and oscillating at a frequency "f" and voltage "V" with "W" watts loss. At a point in the cycle when the current is zero, the instantaneous voltage will be $\sqrt{2}\,V$; all the energy is stored in the condenser and its amount is $C\,V^2$. The r.m.s. current in this circuit is $2\pi f C\,V$, and the joules lost per cycle are W/f. Dividing energy stored by joules lost per cycle gives:

$$\frac{\text{Energy stored}}{\text{Energy lost per cycle}} = \frac{CV^2}{W/f} = \frac{fCV^2}{W} = \frac{2\pi fCV^2}{2\pi W} = \frac{VI}{2\pi W}$$

which shows that the ratio of energy stored to energy dissipated per cycle is $\frac{1}{2\pi}$ times the ratio of reactive power to watts. Circuits having less than twice as much energy stored in them as they dissipate per cycle tend to be erratic in operation. Circuits having more than this amount of energy stored in them may have disproportionate resistance loss. Unless, therefore, there is some other determining factor, circulating volt-amperes should approximate 4π times the power. Another way of saying this is that power factor should not be over 8 percent, or that decrement should not exceed 0.25. This circulating energy has the same effect as the flywheel of a single acting engine and must be coupled closely to the plate.

After assurance is obtained that circulating energy is adequate, oscillator design in general is only a matter of determining proper voltages and phase relations. For the tube which has already been used as an example, the rated output is 1 kilowatt at 10,000 volts direct current. The characteristic voltages from Figure 6 are:

Minimum plate 800 volts, from which r.m.s. value of alternating current potential is	6,500
R.M.S. Grid Volts	1,050 volts
Grid Bias	920 volts
Grid Leak Resistance	20,000 ohms
Loss in tube (Figure 5)	220 watts
Efficiency	79.5 percent

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Suppose we wish to design a simple Hartley circuit to meet these conditions. The circuit is shown in Figure 19. In this figure:

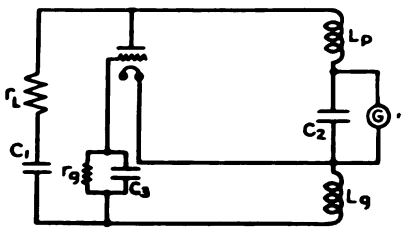

FIGURE 19—Hartley Circuit

L_p = plate inductance.
L_g = grid inductance.
C_1 = tuning condenser.
C_2 = direct current blocking condenser.
C_3 = grid blocking condenser
r_g = grid leak resistance.
r_1 = load resistance.
G = direct current energy source.

To meet the tube requirements

$$L_p / L_g = \frac{6500}{1050}, \quad r_g = 20{,}000 \text{ ohms.}$$

Suppose the desired frequency to be 10^6 cycles, and that a maximum of energy is to be delivered to r_1. With an output of 1 kilowatt, circulating kilovolt-amperes should be 4π or 12.5 kilovolt-amperes.

$X_{L_p} = \frac{E_p^2}{Va} = \frac{6500^2}{12500} = 3{,}380$ ohms, at 10^6 cycles. $L_p = 0.538$ millihenry.

$X_{L_g} = X_{L_p} \times \frac{1050}{6500} = 545$ ohms, at 10^6 cycles. $L_g = 0.087$ millihenry.

$X_{C_1} = X_{L_p} + X_{L_g} = 3{,}925$ ohms, at 10^6 cycles. $C_1 = 4.06 \times 10^{-5}$ mfd.

Circulating current is $\frac{12500}{6500} = 1.925$ amperes.

The total resistance of the circuit is $\frac{1060}{1.925^2} = 270$ ohms.

From this, if we measure the radio frequency resistance of

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L_p, L_g, C_1, and connecting wires, r_1 can be obtained. Suppose the inductances have power factors of 1 percent, and that the condensers and leads have negligible loss

$$r_1 = 270 - 39.3 = 230.7 \text{ ohms.}$$

There is an almost infinite variety of circuit arrangements containing but one tuning which are solved by the same method as indicated above. The voltages may be obtained by self-induction, drop across capacities or mutual effects and, so long as the plate and grid voltages are obtained in the proper phase and the circuit is not overloaded, correct operation should be obtained. C_2 and C_3 are not critical.

If the experimenter does not secure the results expected, there are two causes more usually encountered than others: The tube may not correspond to the characteristics, or the circuit constants may not be as they seem. The most frequent tube variation is emission. If this is low, performance will not be obtained. If emission is high, tube life may be extended by lowering the filament current. Output and efficiency can both be increased at the expense of life by overburning the filament.

A three-element tube is ready to function at almost any frequency. At high frequencies, inductances may perform as capacities if their natural frequencies are exceeded. Condenser leads may have more inductive impedance than the capacity impedance of the condensers to which they are attached. Circuits may oscillate by parts, and so on. At high frequencies, skin effects increase resistance and surrounding objects may affect resistance, inductance, or capacity. All such parasitic phenomena must be considered or eliminated before the true performance is obtained.

Grid Phase Angle Corrections

A discussion of circuit design is not complete without a treatment of the phenomena which make pliotron oscillators run at a frequency other than the natural resonant frequency of the circuits. The factors entering into the selection of plate blocking condensers and chokes also deserve some detailed analysis.

A Hartley circuit normally operates at a frequency lower than that determined by the relation

$$f = \frac{1}{2\pi\sqrt{LC}}$$

The reason for this is apparent from Figures 20-A, B, and can be calculated quantitatively.

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Figure 20-A is a composite circuit and voltage diagram. $O\,A$ is the plate voltage vector; the plate is connected at A, the filament at O, and the plate inductance between these points. $O\,B$ is the inductive drop in the grid coil. $B\,C$ the resistance drop, so that $O\,C$ is the grid voltage vector with the grid connected at C. $C\,A$ is the condenser drop. Since resistance in the plate coil does not affect the grid phase angle, it is left out of the diagram, altho its effect is obvious.

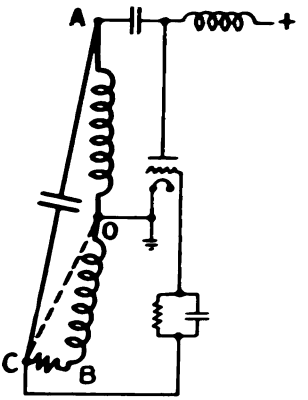

FIGURE 20-A

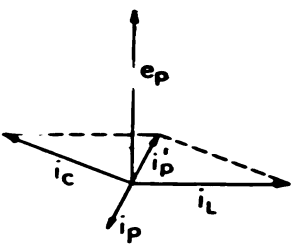

FIGURE 20-B

The plate current is in phase with the grid voltage and is shown as i_p in Figure 20-B. In this figure, i_c is the current thru the circuit $O\,B\,C\,A$, and i_L is the current thru inductance $O\,A$. According to Kirchhoff's law, the vector sum of the currents at any point, such as O, must be zero. Therefore, the sum of i_c and i_L must equal i_p', which is i_p reversed. Now, since i_p has a component leading e_p which adds to the corresponding component of i_c, the value of i_L must be increased, which can be accomplished either by reducing the inductance of the plate coil or lowering the frequency. It follows that a simple Hartley circuit will always operate below the resonant point and that the amount of frequency drop can be calculated by applying numerical values to the vectors shown in Figure 20-B.

By the same reasoning the operation of a Colpitts' circuit can be analyzed as in Figures 21-A, B.

As before, Figure 21-A is the voltage and circuit diagram, with plate at A, filament at O, and grid at C. In this case the component of plate current is in phase with i_L so that it must be balanced by an increased current in the plate condenser. This requires either a larger plate condenser or a higher frequency

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so that a Colpitts' circuit always operates above the resonant point by an amount which can be calculated by applying numerical values to the vectors.

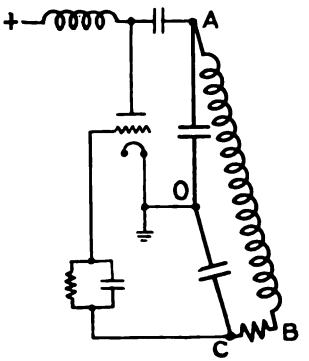

FIGURE 21-A

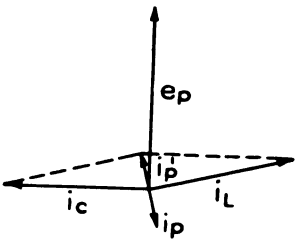

FIGURE 21-B

The diagrams Figures 22-A, B show the effect of the plate blocking condenser and line choke on the operation of a Hartley circuit. In Figure 22-A, *O A B* and *C* have the same significance as in Figure 20-A. *A D* is the alternating current component of the drop across the blocking condenser. The plate is now at-

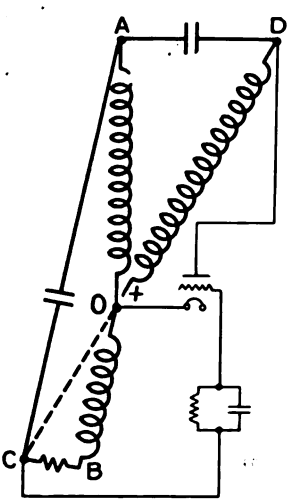

FIGURE 22-A

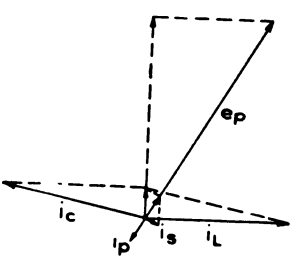

FIGURE 22-B

tached to *D* instead of to *A*. *O D* is the alternating component of drop across the line choke. The direct current is introduced

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between O and D, but does not appear in the diagram, which represents only alternating vectors. Figure 22-B is similar to 20-B, except for the added current in the choke $O\,D$, which is designated i_s and the change in e_p, which must now be in the direction $O\,D$ instead of $O\,A$.

It is apparent that proper proportioning of blocking condenser and choke may bring the plate voltage back into line with the grid voltage and plate current. Best efficiency is obtained by having plate voltage and current exactly 180° out of phase, as will be apparent by reference to Chapter I. If the 180° relation is not maintained, the step integration must be carried over the entire duration of current flow and, since maximum current will no longer correspond to minimum voltage, the integrated product is necessarily larger. The line choke and blocking condenser should, therefore, be included in the circuit design.

To do this the circuit $O\,B\,C\,A$ is calculated as tho choke and blocking condenser were not present. This circuit may be equivalent either to a pure resistance or to a resistance and reactance in series. Let it be proportioned so that it will be equivalent to a resistance. The angle $C\,O\,A$ can then be calculated and its supplement $A\,O\,D$. Since the equivalent resistance between A and O is known, the capacity reactance $A\,D$ is selected so that $A\,D/O\,A = tan^{-1}\,(180° - A\,O\,C)$. The circuit voltage is impressed at D and the circuit $D\,A\,O$ will draw some leading current, the amount being easily ascertainable. It is then only necessary to choose the choke $D\,O$ of such a value that it wili draw the same amount of lagging current.

The procedure in arriving at the proper values of blocking condenser and line choke will be clearer if a numerical example is carried through.

In the first place it is necessary to secure the proper grid excitation ratio.

Let
$$\frac{E_p}{E_g} = \frac{O\,A}{O\,C} = 4.$$

Since $O\,D$ is the plate voltage, it may be necessary to make a second approximation if $O\,D$ is seriously different from $O\,A$.

Let $O\,A = 100$ ohms inductance. 10 ohms resistance.

$O\,B = 25$ ohms inductance.

$B\,C = 2.5$ ohms resistance.

$C\,A = 125$ ohms capacity.

Then Angle $O\,A\,C = sin^{-1}\dfrac{2.5}{100} = 1°\,27'$

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If 100 volts be impressed across OA

$$i_L = 1, \quad \text{Watts in } OA = i_L^2 \times 10 = 10.$$

$$i_c = 1, \quad \text{Watts in } BC = i_c^2 \times 2.5 = \frac{2.5}{12.5}.$$

Equivalent resistance $\frac{E^2}{W} = \frac{100^2}{12.5} = 800$ ohms. We may adjust to have this circuit operate at the resonant point so that its reactance is zero.

By the sine rule:

$$\frac{OA}{Sin\, C} = \frac{OC}{Sin\, A} = \frac{AC}{Sin\, O}$$

$$\frac{100}{Sin\, C} = \frac{0.25}{0.025}, \qquad Sin\, C = 0.1, \qquad C = 5° 45'$$

Angle $AOD = A + C = 6° 55'$

$$AD = AO\, tan\, AOD$$

$$= 800 \times 0.1 = 80 \text{ ohms capacitance.}$$

The total impedance DAO is, therefore, 804 ohms, so that the grid voltage ratio is nearly correct. If we impress 100 volts between D and O, the current is

$$\frac{100}{804} = 0.124 \text{ amperes}$$

And the wattless volt-ampere component is

$$0.124^2 \times 80 = 1.23 \text{ volt-amperes.}$$

In order to correct for these leading volt-amperes, the choke should draw the same amount lagging

$$DO = \frac{100^2}{1.23} = 8{,}130 \text{ ohms.}$$

If the impedance of the plate blocking condenser had been high, the assumed ratio between grid and plate voltages would not have been obtained. It would then have been necessary to assume an initial value somewhat larger than desired for the final result, proceeding by a series of approximations. However, it is not likely that a high impedance blocking condenser would be desirable for other reasons. A high impedance blocking condenser corresponds to a low impedance choke which would allow radio frequency currents to flow in higher loss circuits and possibly damage power generating apparatus.

Proportioning the plate blocking condenser and line choke is not the only method of bringing plate voltage and current into the 180° relation. The angle OAC may be compensated

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for by dephasing the grid in such a way as to cause the oscillations to occur at the natural resonant frequency and the plate current and voltage to be properly related.

Figures 23-A and 23-B are two methods by which a Hartley circuit may be restored to operation at the natural resonant frequency of the circuit with proper phase relations, while Figures 23-C and 23-D are the two equivalent methods for the Colpitts' circuit.

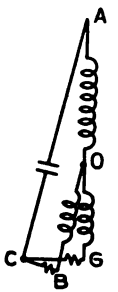

FIGURE 23-A

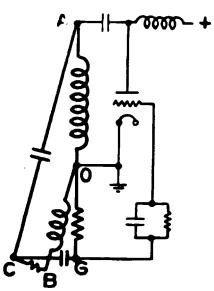

FIGURE 23-B

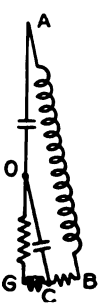

FIGURE 23-C

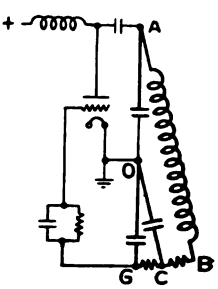

FIGURE 23-D

In Figure 23-A, the phasing is accomplished by connecting resistance *C G* and inductance *G O* in series. The grid is attached at *G*. The same result is accomplished in Figure 23-B by a resistance from *O* to *G* and a condenser from *G* to *C*. The elements are reversed in 23-C and 23-D to produce lag instead of lead.

Altho grid phasing may correct the various angles, it is probable that adjustments of choke and blocking condenser are to be preferred since these devices are normally present and so do not constitute added complication.

GRID BIAS CONDENSER

It will be noted that no criteria have yet been developed governing the choice of grid blocking condenser. Since the function of this condenser is to pass the alternating current component of grid excitation without serious drop while forcing the direct component to flow thru the grid leak or biasing resistance, its value is not critical. Its value should be large enough so that the grid plate capacity is small by comparison. The values of tube capacity are normally so small that this requirement causes no concern. The individual pulses of direct current should cause no considerable change in the bias, but this also causes small concern.

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Intermittent Oscillation

Trouble may be encountered due to excessive capacity of the grid leak condenser. Since the reason for this is not apparent at first glance, it will be developed in more detail. The evidence of trouble is a falling off in input and output and the radiation of an interrupted wave.

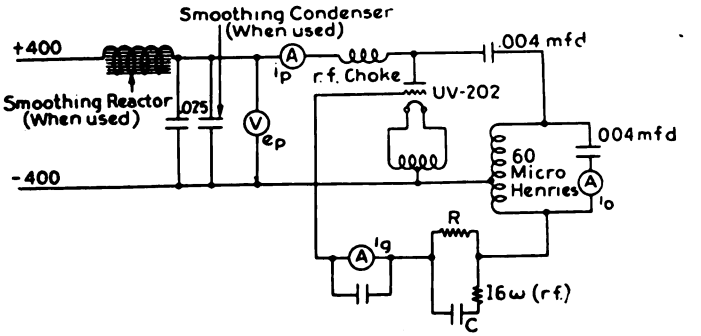

Figure 24—Circuit Used in Taking Films Shown in Figures 26, 27, 28

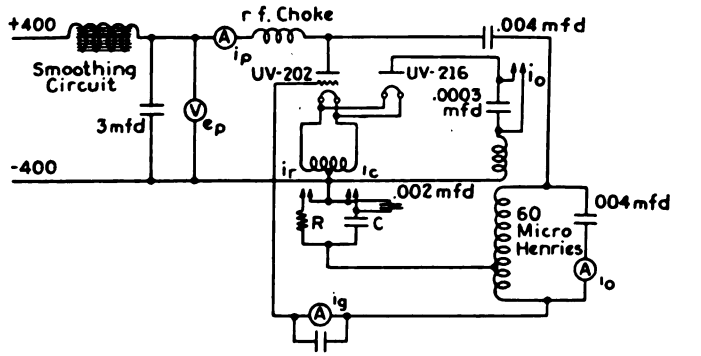

Figure 25—Circuit Used in Taking Film Shown in Figure 29

Oscillogram (Figure 26) shows the result of a very large grid condenser. This film was taken with the circuit shown in Figure 24. The oscillations alternately build up and die out, the period being quite long. By reducing the condenser, the period is changed as shown in Figure 27. The phenomenon exists even when considerable care is used in smoothing out the impressed voltage by means of a filter, as shown in Figure 26. That the phenomenon is not due to resonance is indicated by the irregularities shown in Figure 28. In the foregoing oscillograms, plate current is used as a measure of oscillations. Figure 29 shows that

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the actual oscillation amplitude follows the same general form. This was taken with the circuit shown in Figure 25.

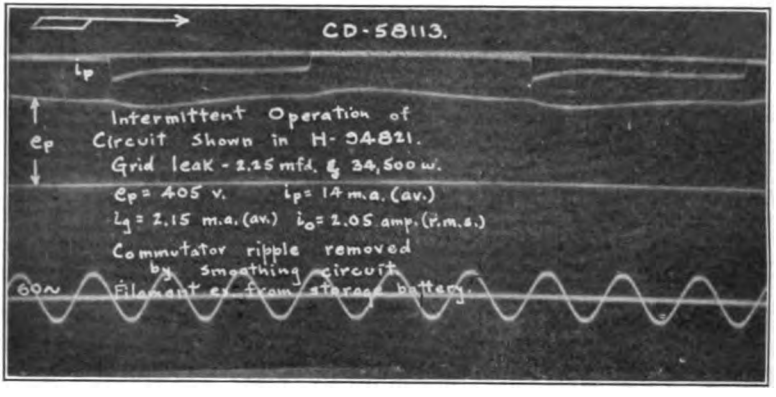
CD-58113.
i_p
e_p
Intermittent Operation of
Circuit Shown in H-94821.
Grid leak - 2.25 mfd. & 34,500 ω.
e_p = 405 v. i_p = 14 m.a. (av.)
i_g = 2.15 m.a. (av.) i_o = 2.05 amp. (r.m.s.)
Commutator ripple removed
by smoothing circuit
60 ~
Filament ex from storage battery.

FIGURE 26

The explanation of this phenomenon is arrived at as follows: Referring to Figure 30, let the ratio of alternating current plate and grid volts, and other adjustments be constant. If we then assume a constant bias in volts, the tube output for any amplitude of oscillations can be calculated directly by the method developed in the first chapter. Several such curves are plotted.

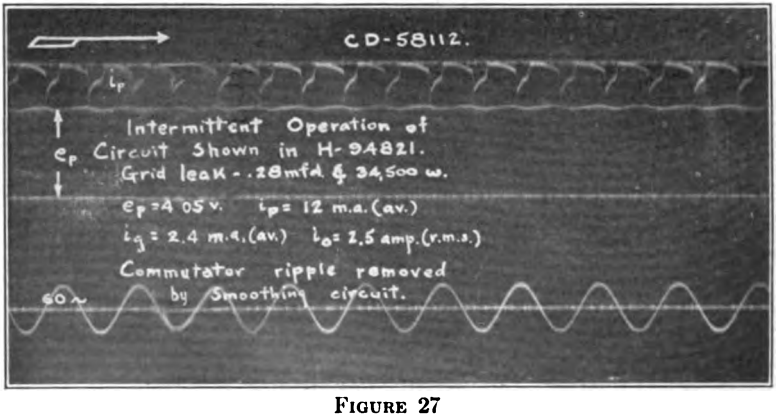
CD-58112.
i_p
e_p
Intermittent Operation of
Circuit Shown in H-94821.
Grid leak - .28 mfd. & 34,500 ω.
e_p = 405 v. i_p = 12 m.a. (av.)
i_g = 2.4 m.a. (av.) i_o = 2.5 amp. (r.m.s.)
Commutator ripple removed
by smoothing circuit.
60 ~

FIGURE 27

The resistance loss in the circuit is a square curve and is also plotted. An intersection between tube output and circuit loss represents a point of equilibrium. If a decrease in oscillation amplitude causes the tube output to become higher than the losses, the point is stable. If the reverse is the case, it is unstable. By de-

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termining the grid current for various points on the curves of output at constant bias, the corresponding leak resistances can be determined. These points may be joined by curves representing output variation with change in oscillation amplitude at constant leak resistance.

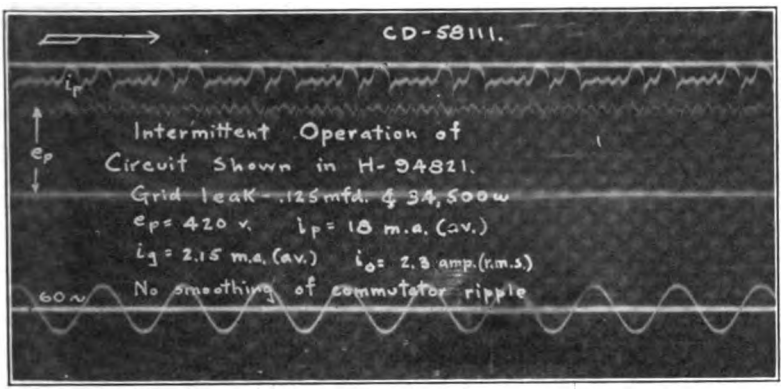
CD-58111.
i_p
e_p
Intermittent Operation of
Circuit Shown in H-94821.
Grid leak - .125 mfd. & 34,500 ω
e_p = 420 v. i_p = 18 m.a. (av.)
i_g = 2.15 m.a. (av.) i_o = 2.3 amp. (r.m.s.)
No smoothing of commutator ripple
60 ~

FIGURE 28

There is a value of bias such that the bias curve and the loss curve are tangent as at C. A greater bias cannot be used as there are no intersections and hence no points of equilibrium.

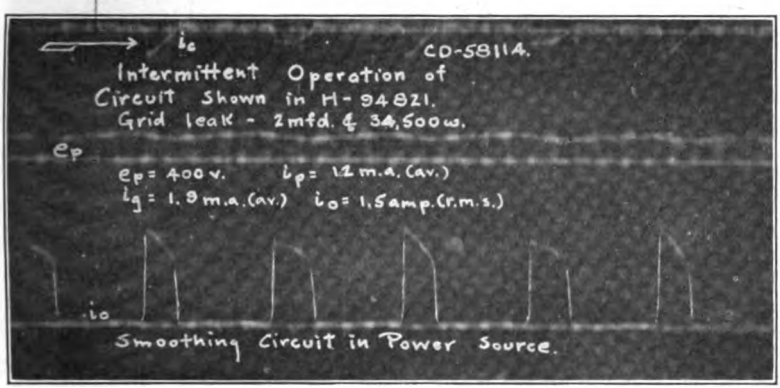
i_o
CD-58114.
Intermittent Operation of
Circuit Shown in H-94821.
Grid leak - 2 mfd. & 34,500 ω.
e_p
e_p = 400 v. i_p = 12 m.a. (av.)
i_g = 1.9 m.a. (av.) i_o = 1.5 amp. (r.m.s.)
i_o
Smoothing Circuit in Power Source.

FIGURE 29

Thru any point as A or B on the loss curve two lines can be drawn, one representing the direction of output variations at constant bias and the other the output variation at constant leak resistance. If a fixed bias is being used, the equilibrium test must be applied to the fixed bias line. If resistance bias is being used,

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the test is applied with reference to the constant resistance line. The grid blocking condenser tends to hold constant bias, therefore with a large condenser, operation as far as equilibrium is concerned, approaches a constant bias line.

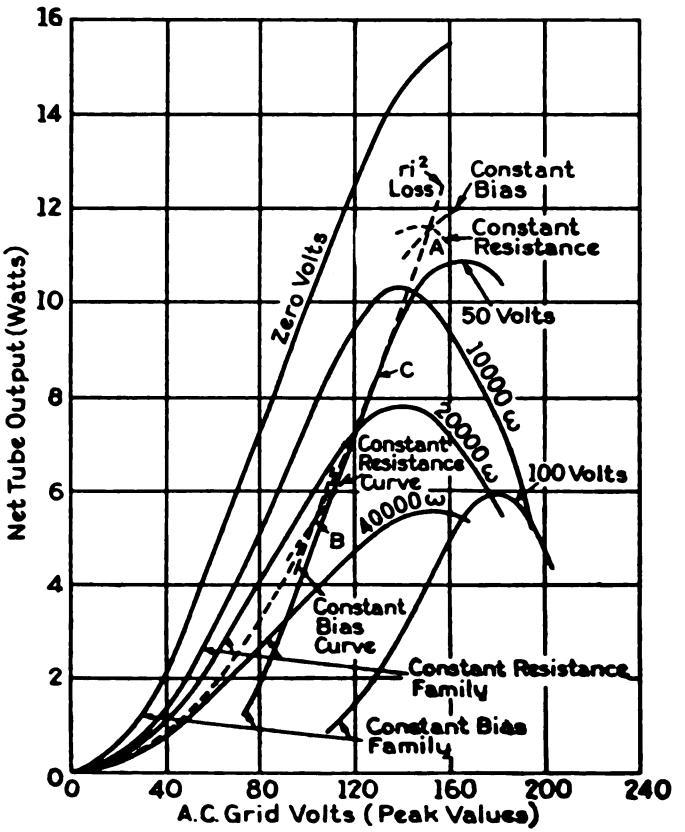

FIGURE 30—Curves Showing Grid Circuit Stability of a UV-202 Tube Assuming Alternating Current Plate Volts are 1.7 Alternating Current Grid Volts and Direct Current Plate Volts are 350

For a small grid condenser, the constant resistance line is more nearly the criterion of stability. It is apparent that in the region from *C*, in the direction of point *A*, stable operation is obtained with either constant resistance or constant bias. In the direction *B*, constant bias operation is unstable, while constant resistance operation is still stable.

Best operation, especially for a highly efficient tube, is very likely to fall in the *C B* zone so that stability requires a grid condenser small enough to cause the slope of the resultant curve for the rate of amplitude variation likely to take place to be less

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than the slope of the loss curve. The condition is also frequently observed in regenerative receiver sets.

Having established a condition of either instability or a very narrow margin of stability, equilibrium may be disturbed by a large number of causes, including generator ripple, line regulation, keying, and the like. The cycle followed is somewhat as follows: Assuming the 20,000-ohm value of grid leak, the tube starting with zero bias will build up both oscillations and grid bias until equilibrium is reached at 7.3 watts output and approximately 50 volts bias. If the grid condenser is small, the operation will be stable. If the condenser is large, any momentary disturbance will shift the operating point up or down on the 50-volt bias line, the condenser tending to hold the bias constant over a brief interval. If it shifts down, the tube output becomes less than the circuit losses, and the oscillations die out. The grid condenser then discharges thru the leak until the bias is low enough for oscillations to start again. The cycle is then repeated.

(To be continued)

SUMMARY—Chapter I. The performance of an oscillating pliotron is determined by accertaining at intervals of a few degrees the instantaneous plate loss, grid loss, input, and so on. These values are then averaged over the cycle to determine tube output and efficiency. By performing this operation with a variety of plate and grid voltages, the optimum conditions for a given output are obtained. In this way a combination of plate and grid voltages and grid bias is obtained which is independent of frequency and can be used for the design of any free oscillating circuit where sinusoidal plate and grid voltages are obtained 180 degrees out of phase. It is shown that the conditions of starting of oscillations can be obtained by assuming zero grid bias and determining the circuit resistance which will just absorb the tube output for small amplitude oscillations. The phenomenon of "blocking" is shown to be due to secondary electron emission from the grid. By knowing under what conditions this secondary emission takes place the circuit may be so designed that all will not occur simultaneously.

Chapter II. For qualitative investigations of vacuum tube performance the plate circuit is assumed to be a portion of a sine wave. This permits mathematical integration to be substituted for the step-by-step integration of the first chapter. By using the mathematical form a qualitative investigation of the effects of space charge, variations in plate voltage and other factors can be made. Where a bird's-eye-view is required this method gives much quicker results than the exact method.

Chapter III. In this chapter it is shown how simple circuits may be designed from data determined by the methods of Chapter I. A resonant circuit is selected in which a circulating current will build up a voltage equal to or greater than that required for grid plus plate excitation without absorbing more than tube output in resistance loss. The circulating voltamperes should not be less than 4π times the watts. Having met these requirements, the plate, filament, and grid are attached either to the inductance or capacity in such a way as to give the proper voltage division. Some phase displacement of grid excitation from 180 degrees may occur. Connections are given by which the grid phase can be corrected to exactly 180 degrees. The proper selection of chokes and blocking condenser may correct such displacement. Too large a grid condenser may cause intermittent oscillation. The mechanics of this phenomenon are described in detail because of its occurrence in regenerative receivers.

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DIGESTS OF UNITED STATES PATENTS RELATING TO RADIO TELEGRAPHY AND TELEPHONY*

ISSUED FEBRUARY 27, 1923–APRIL 17, 1923

BY

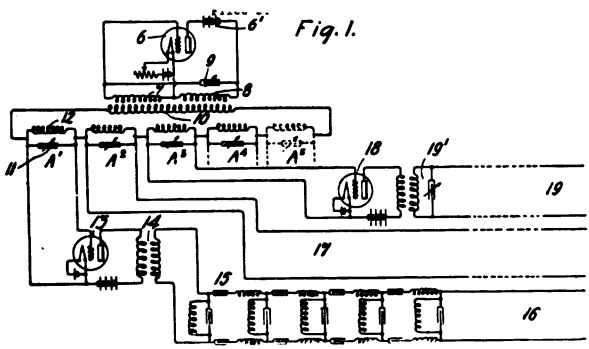
JOHN B. BRADY

(PATENT LAWYER, OURAY BUILDING, WASHINGTON, D. C.)

1,446,650—B. Macpherson, filed October 22, 1919, issued February 27, 1923. Assigned to Wireless Specialty Apparatus Company.

ELECTRICAL CONDENSER, comprising alternate sheets of foil and dielectric with pressure plates upon opposite ends of the stack and resilient strips, or bands of insulating material extending around the pressure plates whereby the band may be placed under tension to maintain the alternate sheets of the condenser in intimate contact.

1,446,752—B. W. Kendall, filed December 29, 1916, issued February 27, 1923. Assigned to Western Electric Company, Incorporated.



NUMBER 1,446,752—Generator and the Generation of Multiple Frequencies

GENERATOR AND THE GENERATION OF MULTIPLE FREQUENCIES, by distortion of the wave form of the fundamental

*Received by the Editor, May 10, 1923.

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frequency and by selecting the overtones or multiple frequencies present in the distorted wave for various uses, such as carrier waves in multiplex signaling. An electron tube generator is employed and continuously overloaded to produce a distorted wave comprising the desired harmonics which are selected and amplified for delivery to separate signaling channels.

1,446,890—L. Espenschied, filed June 7, 1918, issued February 27, 1923. Assigned to American Telephone and Telegraph Company.

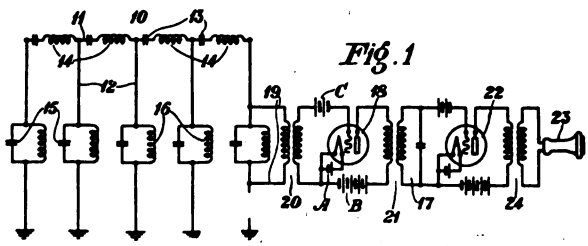

Fig. 1

NUMBER 1,446,890—Radio Receiving Apparatus

RADIO RECEIVING APPARATUS arranged for eliminating or minimizing the effects of static disturbances. The invention proposes to avoid such disturbance by changing or diverting the disturbing energy into a plurality of frequencies other than that of the energy to be transmitted ot into a band or frequencies of considerable extent so that, even tho the frequency being transmitted falls within its scope, only a small proportion of the disturbance reaches the translating or indicating devices of the system. This is accomplished by employing a wave filter form of antenna as illustrated in the cut.

1,447,165—F. A. Kolster, filed January 30, 1919, issued February 27, 1923.

RADIO METHOD AND APPARATUS, in which a closed loop circuit and an antenna circuit are used for reception of transmitted energy from a signaling station and arranged to combine the received currents to produce a uni-lateral characteristic for observing the direction of the transmitting station.

1,447,204—L. Espenschied, filed September 30, 1919, issued March 6, 1923. Assigned to American Telephone and Telegraph Company.

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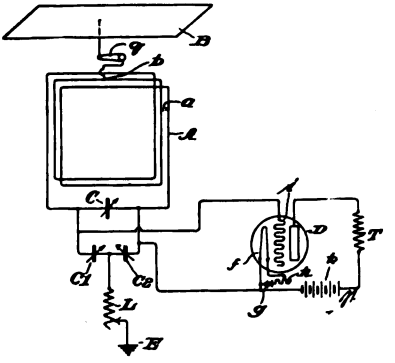

NUMBER 1,447,165—Radio Method and Apparatus

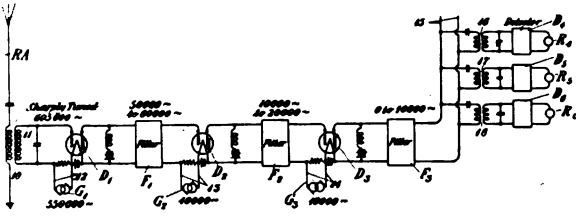

Fig. 5

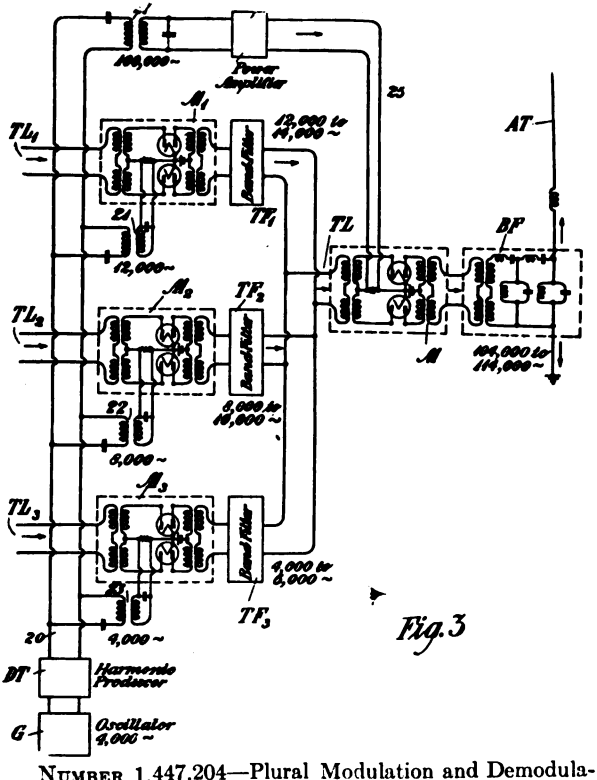

Fig. 3

NUMBER 1,447,204—Plural Modulation and Demodulation Circuits

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PLURAL MODULATION AND DEMODULATION CIRCUITS, for use in multiplex radio systems. It is proposed to generate at the sending station a fundamental frequency and produce harmonics of this fundamental frequency. The lower harmonics are then used as carriers for the first step of modulation and a higher harmonic is used as the carrier for the second step of modulation. At the receiving station either of two things may be done: A fundamental frequency may be independently generated at the receiving station and harmonics may be produced from this fundamental, one of the higher harmonics being used for the first step of frequency translation and lower harmonics used for the final step of frequency translation. By this scheme all of the channels at each station are definitely tied together, since they are related to a fundamental frequency, and it is a matter of relatively simple adjustment to maintain the fundamental frequency at the sending and receiving station the same. An alternative expedient is to detect from the received band of frequencies the fundamental frequency generated at the sending station and produce from this frequency harmonics which may be used in the steps of demodulation, as above described. This expedient not only definitely ties together the frequencies of the various channels at the sending and receiving station, but also rigidly relates the frequencies of corresponding channels at the two stations.

1,447,481—H. Morris-Airey and George Shearing, filed August 22, 1921.

THERMIONIC VALVE construction in which the leads entering the glass envelope of the tube are formed by lead seals. These conductors are formed between the external contacts of the tube and the interior electrodes by running the lead thru a glass tube in a molten condition, which when hardened becomes an effective seal and serves as a connection.

1,447,773—L. Espenschied and Ralph Bown, filed September 15, 1921, issued March 6, 1923. Assigned to American Telephone and Telegraph Company.

RADIO TRANSMISSION CONTROL SYSTEM, which maintains a uniform transmission level by varying the amplification of the receiver to compensate for transmission variations. The regulation at the receiver is automatic. A current limit relay operates at the receiver to actuate a motor driving a contact arm which cuts in or out resistance in the amplifier circuit to maintain the

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volume of received signal constant irrespective of fluctuation in the transmission current.

1,447,779—J. H. Hammond, Jr., filed December 27, 1910, issued March 6, 1923.

System of Ether Wave Control, comprising a transmitting station arranged to emit waves of constant amplitude with a signaling device for increasing the amplitude of said waves. At the receiver the apparatus is arranged to be unresponsive to currents set up by the waves of constant amplitude, but responsive to the waves of increased amplitude. The energy received from these latter waves operates the observing device.

1,447,793—M. Latour, filed August 19, 1921, issued March 6, 1923.

Radio Receiving System, in which the sensitiveness of reception is improved by adjusting the magnetization of the telephones to a selected point. A pair of rectifiers are used in the receiving circuit for improving rectification and increasing sensitiveness in heterodyne reception.

1,448,575—G. H. Stevenson, filed December 21, 1920, issued March 13, 1923. Assigned to Western Electric Company, Incorporated.

Wave Meter and Similar Electrical Device, in which the change in capacity by movement of the control key, normally used to connect the buzzer in the wave meter circuit, is compensated for by substituting an equivalent capacity in the circuit upon operation of the key.

1,449,148—W. F. Gehrig, filed March 9, 1922, issued March 20, 1923. Assigned to Essex Specialty Company, Incorporated.

Detector of the crystal type in which the cat-whisker is adjusted to a sensitive point on the crystal from a support consisting of a split spherical ball bearing. The invention resides in this split spherical bearing, by which the cat-whisker may be readily adjusted to any desired position.

1,449,253—M. S. Strock, filed September 23, 1921, issued March 20, 1923.

Uni-directional Receiving System employing a coil antenna and a ground variable inductor coupled therewith, as absorb-

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ing means for the transmitted energy. The electron tube detector of the receiving apparatus is connected to this collecting system, the filament electrode being connected to the inductor and the grid being connected to the loop.

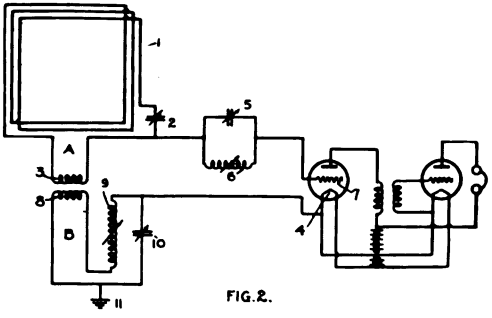


FIG. 2.

NUMBER 1,449,253—Uni-directional Receiving System

1,449,372—H. D. Arnold, filed December 1, 1915, issued March 27, 1923. Assigned to Western Electric Company, Incorporated.

Fig. 1.

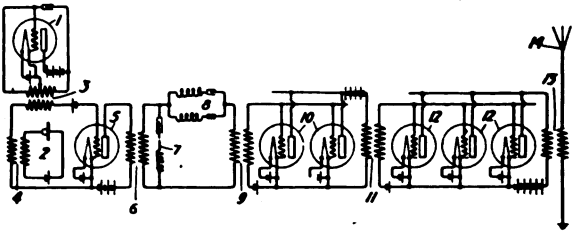
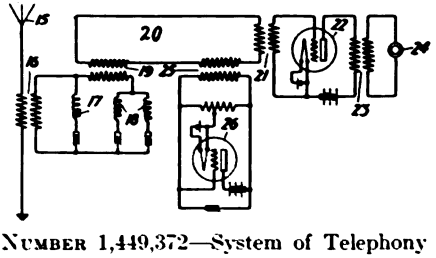


Fig. 2.



NUMBER 1,449,372—System of Telephony

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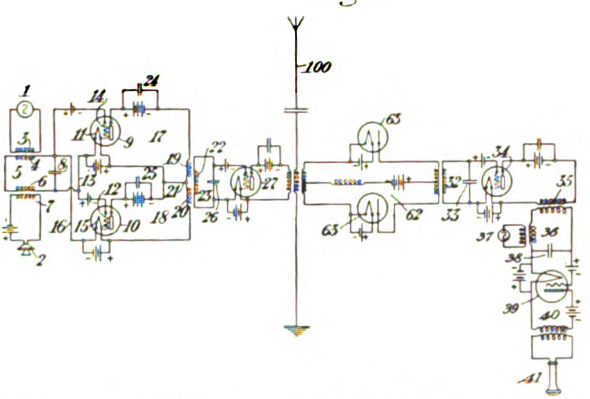
System of Telephony, arranged to increase the efficiency of telephonic communication by modulating a radio frequency oscillation and eliminating from the antenna, or other sending circuit, constant amplitude oscillations of the carrier-wave frequency, which, in present practice, are impressed upon it. Further objects of the inventions are to improve the quality of speech received and to make possible the secret transmission and reception of messages. These objects are accomplished by providing an arrangement of circuits whereby current is suitably modulated and is supplied to the antenna only when the characteristics of the radio frequency current to be impressed on the antenna are changing in accordance with the wave form of the signal to be transmitted, and by providing at the receiving station a small auxiliary generator which shall furnish a wave of the frequency of the unmodulated carrier wave.

1,449,382—J. R. Carson, filed December 1, 1915, issued March 27, 1923. Assigned to American Telephone and Telegraph Company.

Fig. 4.



Number 1,449,382—Method and Means for Signaling with Radio Frequency Waves

Method and Means for Signaling with Radio Frequency Waves in duplex operation and without transmission of energy, except during the time when signals are actually being transmitted. The system contemplates the generation of an audio frequency signaling wave and an undamped radio frequency carrier wave. The carrier is modulated in accordance with the signal wave to produce a modulated wave. the ampli-

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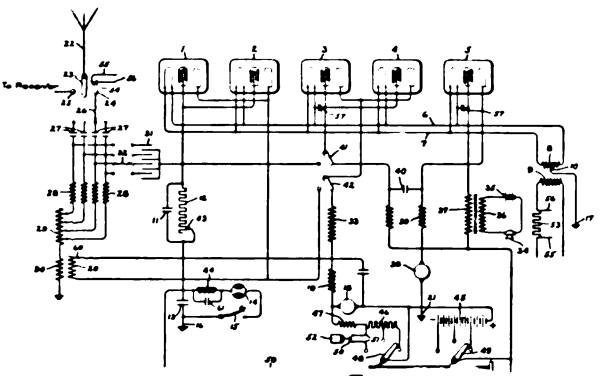
tude of which is directly proportional to the modulating wave. The transmission of energy is automatically prevented in the absence of the signal wave.

1,449,722. W. R. G. Baker, filed September 17, 1921, issued March 27, 1923. Assigned to General Electric Company.



NUMBER 1,449,722—Radio Frequency Signaling System

RADIO FREQUENCY SIGNALING SYSTEM, which may be interchangeably used in the transmission of speech-modulated radio frequency waves as are used in radio telephony, interrupted continuous waves for radio telegraphy, or continuous waves for radio telegraphy. An electron tube transmitter circuit is provided with a switching arrangement whereby the tubes used as modulators in radio telephone transmission may be used as oscillators in circuit with the other oscillators when the set is used for telegraphy.

1,449,911—R. H. Ranger, filed November 12, 1921, issued March 27, 1923. Assigned to Radio Corporation of America.

METHOD AND MEANS OF RECEIVING SIGNALS, consisting in receiving the transmitted signals at a plurality of stations and comparing the signals received at the same station to eliminate errors and effects of static interference.

1,450,038—G. Hill, filed April 28, 1920, issued March 27, 1923.

COMBINED WAVE CHANGER AND WAVE METER, involving a method of having the indicating pointer of the wavemeter which indicates the wave length on the various scales so combined with the wave changer that as the handle of the wave changer is

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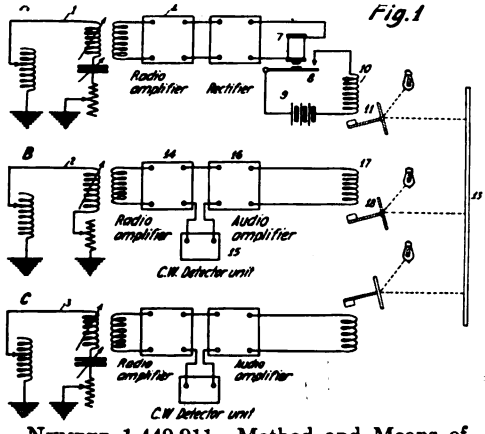
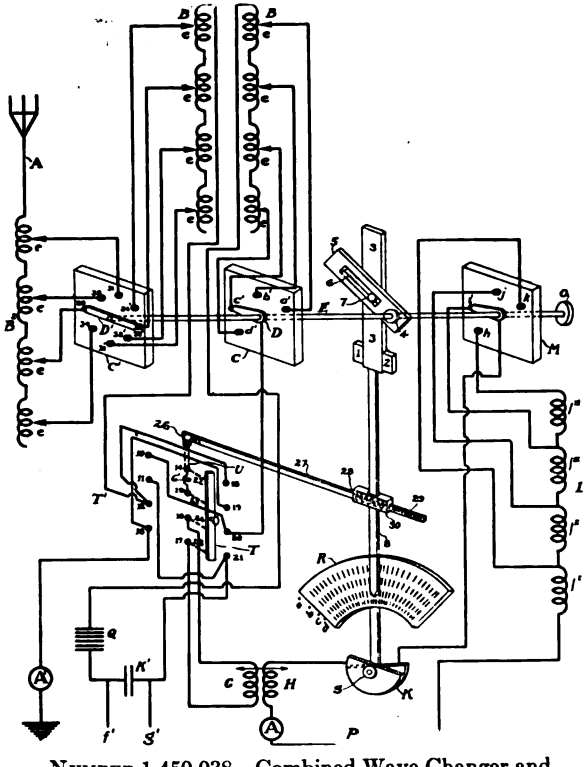
operated, the pointer for the wavemeter is operated and picks out or selects the proper scale.



NUMBER 1,449,911—Method and Means of Receiving Signals



NUMBER 1,450,038—Combined Wave Changer and Wave Meter

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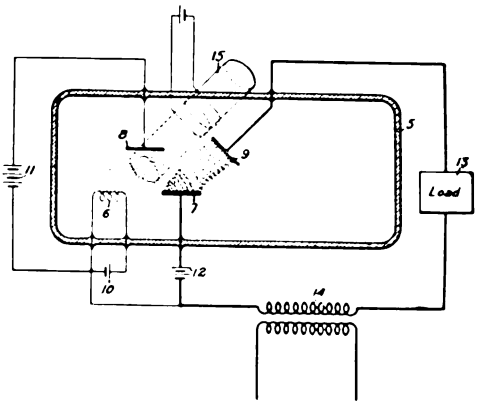
1,450,061—W. W. Coblentz, filed August 6, 1920, issued March 27, 1923.

Optical Method for Producing Pulsating Electric Current, for signaling by light rays. The method consists in successively exposing a light sensitive body to light rays which are colored to effect alternate photo-positive and photo-negative action by the body whereby the current passing therethru is modulated accordingly.

1,450,265—J. Slepian, filed April 18, 1919, issued April 3, 1923. Assigned to Westinghouse Electric and Manufacturing Company.



Number 1,450,265—Hot Cathode Tube

Hot Cathode Tube for rectification, in which a relatively small incandescing filament may be operated at moderate temperatures to produce a small number of electrons and these electrons may be caused to impinge upon an adjacent electrode with high velocity by subjecting them to the influence of a high voltage electrostatic field. As a result, there is produced a profuse emission of electrons from the adjacent electrode by the joint action of reflection and secondary emission, it being well known that the impact of a high-velocity electron upon another body may set free a large number of low-velocity electrons therefrom. The adjacent electrode, which is thus caused to be the seat of a profuse electron emission, may now be employed as a cathode in an auxiliary circuit, and a relatively large amount of current may be offered passage in one direction because of the large number of electrons available.

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1,450,413—H. W. Edmundson, filed March 10, 1919, issued April 3, 1923. Assigned to General Electric Company.

VACUUM ELECTRIC DISCHARGE DEVICE, in which a shield is provided to block the discharge of electrons from the cathode in the direction of the leading-in conductors in the tube. The patentee does away with the continued electron bombardment in the direction of the glass press in the tube containing the leading-in wires, as the tendency of depositing a conductive film between the leading-in wires, impairs the efficiency of the tube. The shield prevents bombardment in the direction of the press.

1,450,749—G. W. Pierce, filed March 11, 1914, issued April 3, 1923. Assigned to Peter Cooper Hewitt; the Farmers Loan and Trust Company of New York, executors of said Peter Cooper Hewitt.

APPARATUS FOR AND METHOD OF CONTROLLING ELECTRIC CURRENTS, comprising a mercury vapor circuit. The invention is illustrated in connection with a radio receiving circuit wherein the mercury vapor tube is rendered particularly sensitive to received signals.

1,451,426—L. J. Lesh, filed April 9, 1918, issued April 10, 1923. Assigned to Emil J. Simon.

SPARK GAP APPARATUS employing quench gap units supported in separate resilient holders, whereby each unit is removable whereupon the holder closes the circuit originally occupied by the gap. Each quench gap unit is provided with heat dissipating ribs.

1,451,427—L. J. Lesh, filed June 5, 1918, issued April 10, 1923. Assigned to Emil J. Simon.

SPARK GAP APPARATUS, comprising individual quench gap units which are arranged radially about a support. The spark gap units are each independently removable from the radial frame and are positioned somewhat like the spokes of a wheel. A selector switch is provided for connecting the desired number of units in the transmitter circuit.

1,452,032—J. F. Farrington, filed April 30, 1918, issued April 17, 1923. Assigned to Western Electric Company, Incorporated.

OSCILLATION GENERATOR FOR SIGNALING SYSTEMS, wherein

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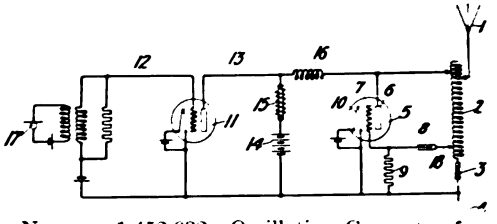
the oscillator is connected with an antenna system, which includes an inductance and capacity, by a particular connection of the input circuit of the tube and the antenna system. The input circuit of the tube is connected across the capacity and a variable connection is provided between one terminal of the input circuit and the inductance in the antenna system.



NUMBER 1,452,032—Oscillation Generator for Signaling Systems

1,452,064—V. Bush, filed November 22, 1918, issued April 17, 1923. American Radio and Research Corporation.

RADIO TRANSMITTER of the impact excitation type in which a series of uni-directional pulses are produced. The primary and secondary circuits are closely coupled and detuned. The spark gap comprises a series of relatively high sparking length gaps with a capacity, resistance, reactance or impedance connected across a portion of the gap such that the primary circuit has a high resistance to the resurgence of current thru the gap at radio frequency and oscillations after the first impacts are damped out.

1,452,339—R. A. Heising, filed May 28, 1918, issued April 17, 1923. Assigned to Western Electric Company, Incorporated.

ELECTRICAL DISCHARGE DEVICE, including an electron tube circuit in which the leak path between the cathode and the grid consists of a highly inductive reactance. This leak path is also shown as comprising an inductance in series with a parallel arrangement of capacity and resistance.

This patent should be considered with previous digests.

1,443,469—J. Guthrie and John W. Simmons, filed August 4, 1922, issued January 30, 1923. Assigned to Simmons Manufacturing Company.

RHEOSTAT particularly adapted for electron tube filament

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control wherein fine adjustment may be desirable. The rheostat comprises a series of resistance disks supported in a container. A plunger operates to vary the pressure on the disks according to predetermined ratio, thereby varying the conductivity of the pile.

List of Radio Trade Marks Published by Patent Office Prior to Registration

The numbers given are serial numbers of pending applications:

170,633—"3YQ, Federal Radio, Camden, N. J." in ornamental design, for radio receiving apparatus. Federal Institute of Radio Telegraphy, Camden, New Jersey. Claims use since on or about April 1, 1922. Published February 27, 1923.

165,755—"Cat's Whiskers" with design of cat's face, for radio receiving apparatus. A. J. Meyer Mfg. Co., Inc., West Hoboken, New Jersey. Claims use since on or about May 20, 1922. Published March 6, 1923.

172,357—"RW" in ornamental design, for radio receiving sets. R-W Mfg. Co., Chicago, Illinois. Claims use since October 14, 1922. Published March 6, 1923.

168,529—"The Clarion," Marfield Radio Mfg. Co., for radio receiving apparatus. Maurice W. Hirshfield, New York. Claims use since July 1, 1922. Published March 27, 1923.

169,825—"Radio Waves," monthly magazine. Radio Waves Publishing Co., Portland, Oregon. Claims use since March 20, 1922. Published March 27, 1923.

171,433—"Mor-Tone" for mica condensers. Radio Supply & Service Corp., New York, N. Y. Claims use since June 16, 1922. Published March 27, 1923.

172,983—"Freco" for radio receiving apparatus. Fallkill Radio & Electrical Co., Poughkeepsie, New York. Claims use since June 15, 1922. Published March 27, 1923.

174,548—"Jewell" for radio receiving sets. Frederic Wommer, Minneapolis, Minnesota. Claims use since September 16, 1922. Published March 27, 1923.

174,260—"RFL" for radio receiving apparatus. Radio Fre-

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quency Laboratories, Inc., Boonton, New Jersey. Claims use since December 20, 1922. Published March 27, 1923.

174,253—"RED SEAL" for radio receiving apparatus. Manhattan Electrical Supply Co., Inc., New York, N. Y. Claims use since November 20, 1922. Published March 27, 1923.

174,947—"RADETEC" for crystal detectors. Orrin W. Towner doing business as "Two Laboratories, Kansas City, Missouri." Claims use since October 23, 1922. Published March 27, 1923.

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162,091—"UNION-RADIO-CORPORATION" in ornamental design for Radio Apparatus. Union Radio Corporation, New York, N. Y. Claims use since March 24, 1922. Published April 24, 1923.

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174,657—"KASKADE," for Radio Receiving Outfits. David

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PROCEEDINGS OF
The Institute of Radio Engineers

Volume 11 AUGUST, 1923 Number 4

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RECEIVING MEASUREMENTS AND ATMOSPHERIC DISTURBANCES AT THE UNITED STATES NAVAL RADIO RESEARCH LABORATORY, BUREAU OF STANDARDS, WASHINGTON, MARCH AND APRIL, 1923*

By

L. W. Austin

(United States Naval Radio Research Laboratory, Washington, D.C.)

(*Communication from the International Union for Scientific Radio Telegraphy*)

The April observations indicate the approach of summer conditions by the strengthening of the atmospheric disturbances and by the beginning of the summer fading which has appeared a full month earlier than last year. The belief that the extreme fading of the European stations in Washington is largely local has been strengthened by the frequent observation of the simultaneous weakening of the signals from Radio Central, Long Island. During the portions of the year when European fading is not prominent, the signals from Radio Central show remarkable uniformity in Washington, seldom varying more than ten percent.

In March and April, Lafayette has unfortunately been sending very little during the forenoon (Washington time).

The calculated A.M. intensities (all daylight between stations), assuming 480 amperes for Lafayette and 380 amperes for Nauen, are:

$$E \text{ (Lafayette)} = 31.5 \cdot 10^{-6} \text{ volts/meter and}$$
$$E \text{ (Nauen)} = 15.3 \cdot 10^{-6} \text{ volts/meter}$$

*Received by the Editor, June 4, 1923.

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RATIO OF AVERAGES

λ (meters)	Signal P. M. / A. M.	Disturbance P. M. / A. M.	A. M. Signal / Disturbance	P. M. Signal / Disturbance
	MARCH			
23,400	1.09	1.85	3.06	1.86
12,500	0.89	1.80	2.36	1.16
	APRIL			
23,400	....	2.0	....	0.158
12,500	0.42	2.42	0.56	0.099

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FIELD INTENSITY OF NAUEN AND OF DISTURBANCES ($\lambda = 12{,}500$ m.) IN MARCH, 1923, IN MICROVOLTS PER METER

	10 A. M.		3 P. M.	
Date	Signal	Disturbances	Signal	Disturbances
1	21.0	5.0	38.5	23
2	39.8	6.0	28.5	5
3	40.6	5.6	34.7	8
5	37.2	4.5	25.2	10
6	20.0	8.8	28.5	12
7	37.0	10.0	17.0	26
8	13.8	8.0	32.0	15
9	31.0	3.0	28.7	12
10	28.7	25.0	....	....
12	23.1	10.0	37.1	16
13	15.4	25.0	28.0	30
14	24.5	8.0	*	15
15	26.7	52.0	10.0	155
16	21.9	25.0	30.9	43
17	32.0	10.0	....	....
19	38.5	13.0	43.0	12
20	38.5	10.0	25.5	10
21	39.0	9.0	51.5	25
22	36.3	7.3	34.1	19
23	42.0	12.0	32.0	13
24	36.3	42.0	....	....
26	72.8	13.0	18.5	52
27	51.5	8.0	32.0	23
28	*	8.0	43.0	16
29	*	6.0	36.3	14
30	55.7	6.0	....	....
31	*	52.0	15.0	48
Average	34.3	14.5	30.5	26.2

* = not heard.
.... = not taken.

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FIELD INTENSITY OF LAFAYETTE AND OF DISTURBANCES (λ = 23,400 m.) IN MARCH, 1923, IN MICROVOLTS PER METER

	10 A. .M.		3 P. .M.	
Date	Signal	Disturbances	Signal	Disturbances
1	*	10	125	52
2	*	12	120	10
3	*	12	*	16
5	*	10	90	18
6	70	13	95	28
7	90	20	70	42
8	*	16	85	32
9	*	8	105	15
10	*	53	....	....
12	*	21	95	28
13	*	95	50	56
14	*	21	100	22
15	*	100	29	268
16	*	43	50	86
17	*	19	70	35
19	*	23	140	18
20	*	19	100	16
21	*	16	85	46
22	*	12	100	36
23	85	23	85	26
24	*	73	....	....
26	*	22	85	100
27	*	19	85	45
28	*	15	100	25
29	*	10	95	26
30	*	6	....	....
31	....	....	*	95
Average	81.7	26.6	89	47.6

* = not heard.
.... = not taken.

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FIELD INTENSITY OF NAUEN AND OF DISTURBANCES ($\lambda = 12{,}500$ m.) IN APRIL, 1923, IN MICROVOLTS PER METER

	10 A. .M.		3 P. .M.	
Date	Signal	Disturbances	Signal	Disturbances
2	*	8	*	48
3	30.4	50	43.0	62
4	55.7	52	2.0	350
5	23.1	52	*	95
6	40.5	68	9.0	150
7	43.0	32	17.5	100
9	25.5	29	*	69
10	32.8	80	*	120
11	32.5	150	*	180
12	31.6	55	*	210
13	38.5	240	*	340
14	27.0	50	17.5	69
16	40.5	25	20.0	40
17	17.6	62	5.0	190
18	19.2	18	21.0	100
19	*	26	13.2	89
20	35.5	30	13.6	98
21	13.6	40	*	96
23	24.3	150	*	350
24	36.2	150	4.1	250
25	34.0	45	24.0	70
26	51.5	40	7.7	185
27	53.5	55	11.0	390
28	55.5	25	15.9	95
30	55.5	40	15.0	50
Average	35.5	62.9	15.0	152

* = not heard.

. . . . = not taken.

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FIELD INTENSITY OF LAFAYETTE AND OF DISTURBANCES ($\lambda = 23{,}400$ m.) IN APRIL, 1923, IN MICROVOLTS PER METER

	10 A. M.		3 P. M.	
Date	Signal	Disturbances	Signal	Disturbances
2	*	15	110.0	85
3	*	100	....	....
4	*	120	15.0	580
5	*	98	40.0	240
6	*	280	26.1	210
7	*	70	50.0	180
9	*	60	29.0	160
10	*	185	2.0	200
11	*	240	20.5	360
12	*	120	25.0	390
13	*	290	2.0	500
14	*	80	92.5	60
16	*	52	25.7	190
17	*	125	19.0	280
18	*	28	50.0	175
19	*	44	50.0	120
20	*	65	24.4	145
21	*	85	30.8	188
23	*	340	32.5	430
24	*	260	50.0	420
25	*	80	75.0	130
26	*	82	50.0	300
27	*	100	29.1	....
28	*	55	*	180
30	*	70	*	80
Average	0	121.8	38.5	243.6

* = not heard.

.... = not taken.

SUMMARY: Field intensities of the signals from the Lafayette and Nauen stations, together with the simultaneous strengths of the atmospheric disturbances at Washington are given for March and April, 1923.

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DESCRIPTION OF THE GENERAL ELECTRIC COMPANY'S BROADCASTING STATION AT SCHENECTADY, NEW YORK*

By

W. R. G. Baker

(General Electric Company, Schenectady, New York)

Radio telephone broadcasting transmitters differ in many respects from the commercial type of radio telephone equipment. The general requirements of radio telephone transmitters, used for purposes other than broadcasting, are ordinarily determined by commercial traffic conditions. In this case, the limits of both the electrical and mechanical design are rather definitely fixed by economic and operating conditions. On the other hand the economics of a broadcasting station are indefinite at present, and the method of operating is determined by factors far removed from those governing commercial traffic.

It is logical to expect that broadcasting stations would be somewhat similar to the best class of commercial equipments. There is, however, one very important exception and that is the fact that the broadcasting transmitter has been subjected to numerous refinements which, due to both economic and operating considerations, could not be incorporated in the commercial transmitter. In general, the commercial radio telephone transmitter is required to transmit only the band of voice frequencies necessary to handle commercial telephony. Transmitters for broadcasting purposes must, however, transmit frequencies over a considerable band from the deepest tone of orchestral instruments and organs to the high note of the piccolo flute. The commercial transmitter is required to operate both as a telephone and telegraph set over a considerable range of wave lengths. The control equipment is designed to permit the operating personnel to handle commercial traffic with the minimum amount of switching.

In order to indicate the general similarity between a commercial and a broadcasting telephone transmitter, attention is

* Received by the Editor, January 31, 1923. Presented before The Institute of Radio Engineers, New York, February 7, 1923.

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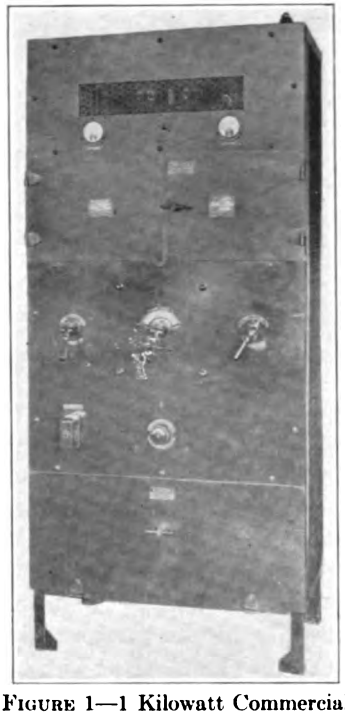

FIGURE 1—1 Kilowatt Commercial Radio Telephone Transmitter

called to Figure 1 which shows the Model AT-702 transmitter built by the General Electric Company for the Radio Corporation of America. This transmitter is designed to provide communication by continuous-wave telegraphy, interrupted continuous-wave telegraphy, and telephony. In this equipment four 250 watt radiotrons (UV-204) shown in Figure 2 are used as oscillators when transmitting continuous waves or interrupted continuous waves. For telephony, two UV-204 radiotrons are

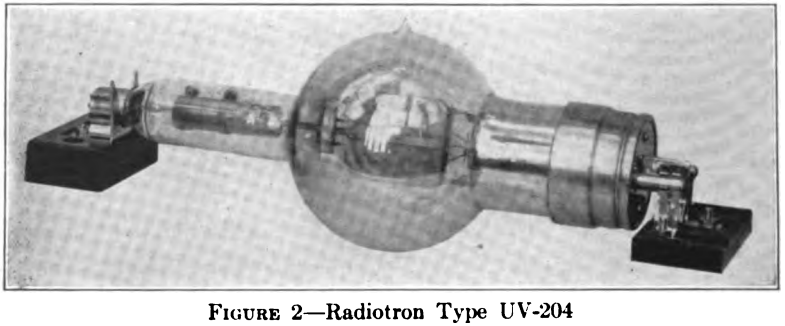

FIGURE 2—Radiotron Type UV-204

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utilized as oscillators, two as modulators and a 50-watt radiotron (UV-203) shown in Figure 3 is employed as a speech amplifier. The set has a normal wave length range of from 300 to 800 meters. Provision, however, is made so that the wave length range may be modified to cover the band of 600 to 2,000 meters, in which case telephony is available up to 1,000 meters and continuous and interrupted wave telegraphy thruout the entire range of wave lengths. On the metal panel forming the front of the unit are mounted various instruments and controls, which are required to handle commercial traffic expeditiously.

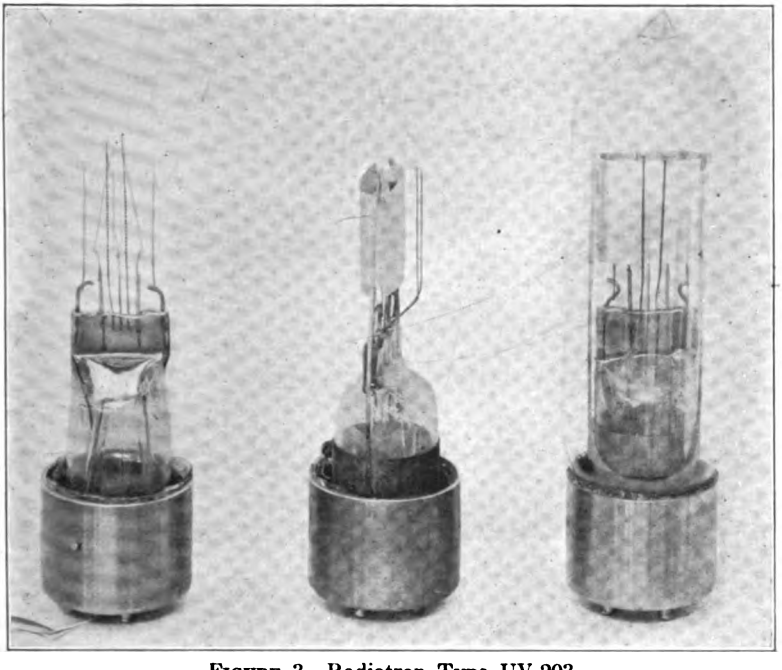

FIGURE 3—Radiotron Type UV-203

The operator's control and the extension station equipment are shown in Figures 4 and 5. The operator's control unit contains switching equipment for starting and stopping the motor-generator. The three-position control switch permits the selection of "Remote," "Local" or "Interphone" operation. With the "Local" position, the operator has complete control of the transmitter. When in the "Remote" position, the "Send-Receive" control is transferred to the subscriber's control unit. When in the "Interphone" position, wire telephony is available between the operator and the extension station.

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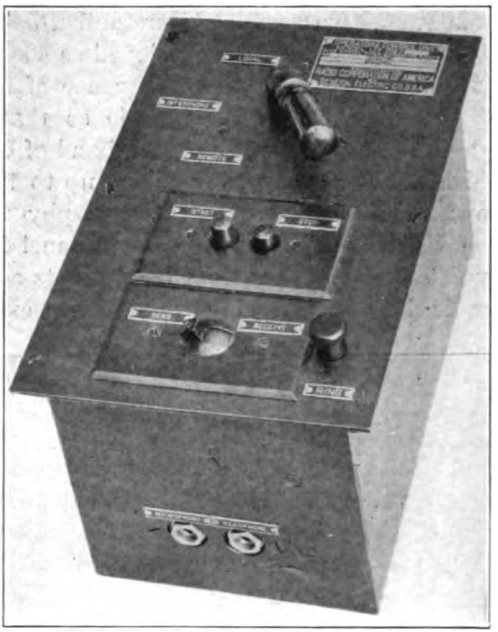

FIGURE 4—Operator's Control Unit for Radio Telephone Transmitter

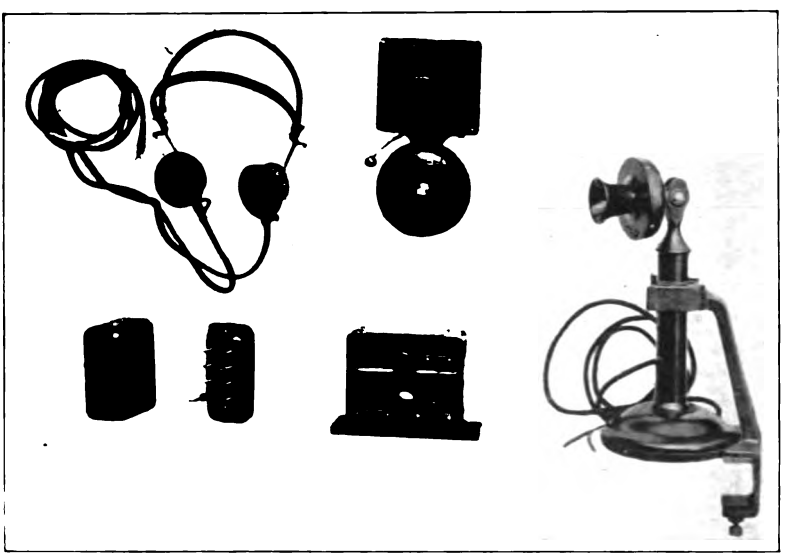

FIGURE 5—Extension Station Equipment for Radio Telephone Transmitter

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The power equipment illustrated in Figure 6 is a three-unit motor-generator set, consisting of a motor, a double-current self-excited generator, and a high voltage direct current generator.

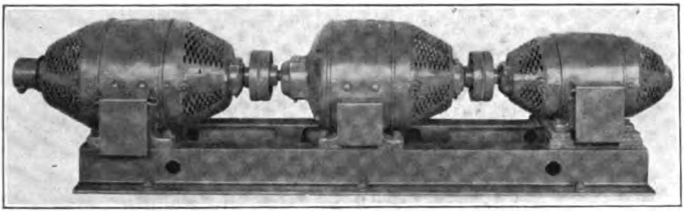

FIGURE 6—2,000 Volt Direct Current Motor Generator Set for Radio Telephone Transmitter

It is evident that a commercial telephone transmitter such as just described must contain the fundamental elements of a broadcasting transmitter. The service requirements, however, are entirely different, hence it would be expected that the detail design of the equipments would vary considerably. Among other requirements, a broadcasting transmitter must deliver radio frequency power at a constant frequency. In addition it must operate at a load point sufficiently high to permit reasonable efficiency without introducing an undue amount of distortion. Such a transmitter unit is shown in Figure 7. In this equipment, the frequency is determined by a tank circuit which in turn is coupled to the antenna circuit. The tube equipment consists of four UV-204 and one UV-203 radiotrons. Two of the UV-204 tubes are employed as oscillators, two as modulators, while the UV-203 is used as a speech amplifier. The control equipment is comparatively simple as only telephony is required and the wave length range is from 300 to 600 meters.

The amplifiers used with this equipment are shown in Figures 8 and 9. Three types are used depending upon the pick-up device employed and the selection to be reproduced. Since this equipment is, in general, quite similar to that used at "WGY"* it will be considered in connection with that station.

The control cabinet, Figure 10, provided with this equipment permits the operating personnel to select either one of two transmitting equipments thus preventing an interruption in case of trouble. In addition, the entire amplifier equipment may be replaced by an emergency group by simply throwing a switch.

The most interesting type of broadcasting stations are those

*Call of the General Electric Company's broadcasting station at Schenectady, New York.

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FIGURE 7—1 Kilowatt Broadcasting Radio Telephone Transmitter

in which continued research and development are carried on, one of which is WGY operated by the General Electric Company at Schenectady, N. Y. It is obvious that a discussion of all the problems incident to the design and operation of a broadcasting station of this type is beyond the scope of this paper. It seems advisable, therefore, to consider the entire equipment in a general way indicating the various features deserving special attention.

The general requirements for the highest grade broadcasting stations are as follows:

1. The station must be ready to operate at all times. This means that the director of broadcasting may at any time handle a special program if he so desires.

2. Continuity of service is absolutely necessary. In other words, the equipment must be designed and operated in a manner that will prevent an interruption during a program.

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3. The quality of transmission must be of the highest order.
4. The transmitter frequency must be maintained constant.

The requirements of a broadcasting station may be summarized by stating that the best possible service must be available at all times.

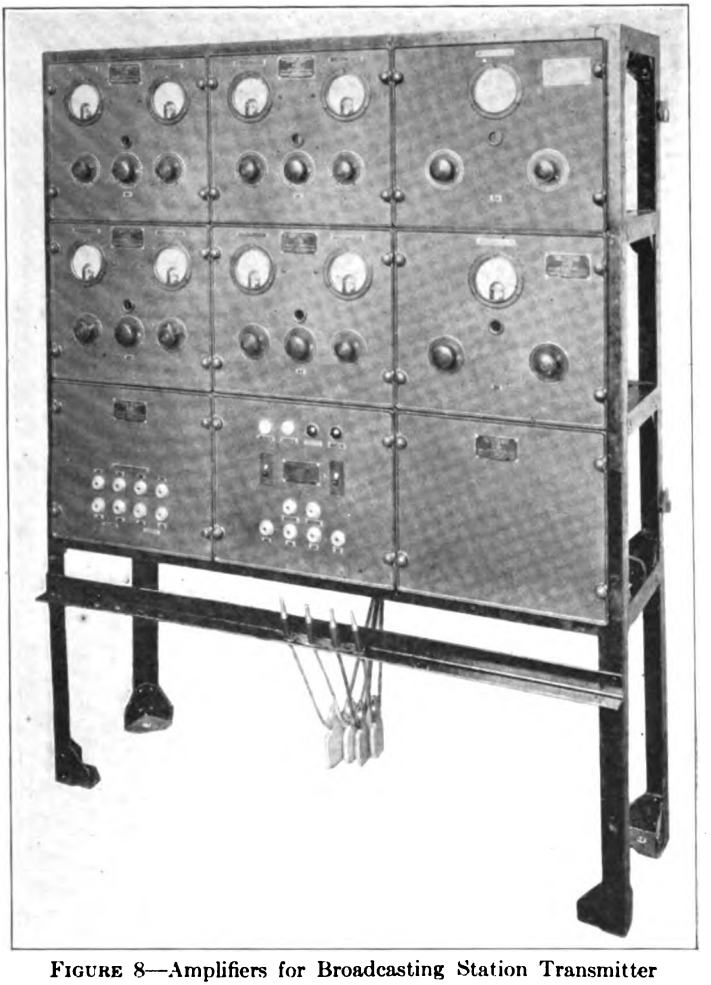

FIGURE 8—Amplifiers for Broadcasting Station Transmitter

In considering station WGY, it is convenient to divide the equipment into three parts.

1. Power Plant.
2. Control Equipment.
3. Studio.

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Power Plant

The power plant includes all equipment necessary for the generation, modulation, and radiation of the radio frequency power. This apparatus is located in what is called the power

Figure 9—Amplifiers for Broadcasting Station Transmitter

house and consists in general of the following equipment, which is provided in duplicate:

(a) High voltage direct current supply consisting of one or more batteries of kenotron rectifiers.

(b) Radio frequency generator utilizing one or more radiotrons as oscillators.

(c) Modulator unit consisting of one or more radiotrons as modulators.

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Control Equipment

The control room contains all amplifying and switching equipment.

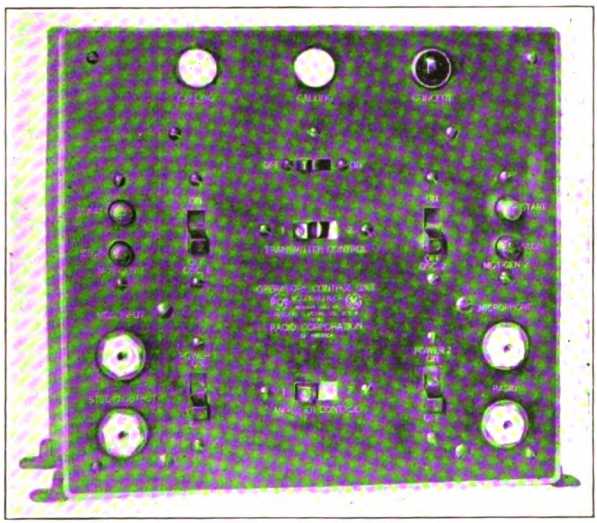

Figure 10—Operator's Control Cabinet for Broadcasting Station Transmitter

Studio

The studio consists of the usual room prepared and furnished especially for broadcasting service.

In Figure 11 is shown the general arrangement of the equipment used at WGY. In order to provide suitable space for the main and auxiliary studios it was necessary to locate this portion of the station 3,000 feet from the power house. While it is not absolutely necessary to locate the control room in close proximity to the studio it was found more convenient to do so in this particular instance.

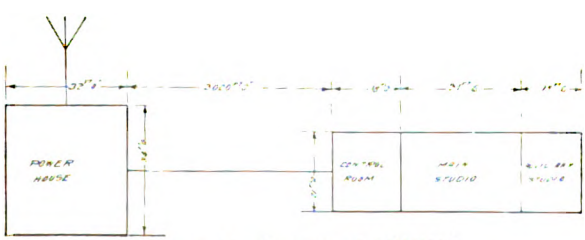

Figure 11—Layout of "WGY"

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THE POWER HOUSE

Antenna

The power house is located in the building shown in Figure 12. This figure also gives some idea of the antenna employed at

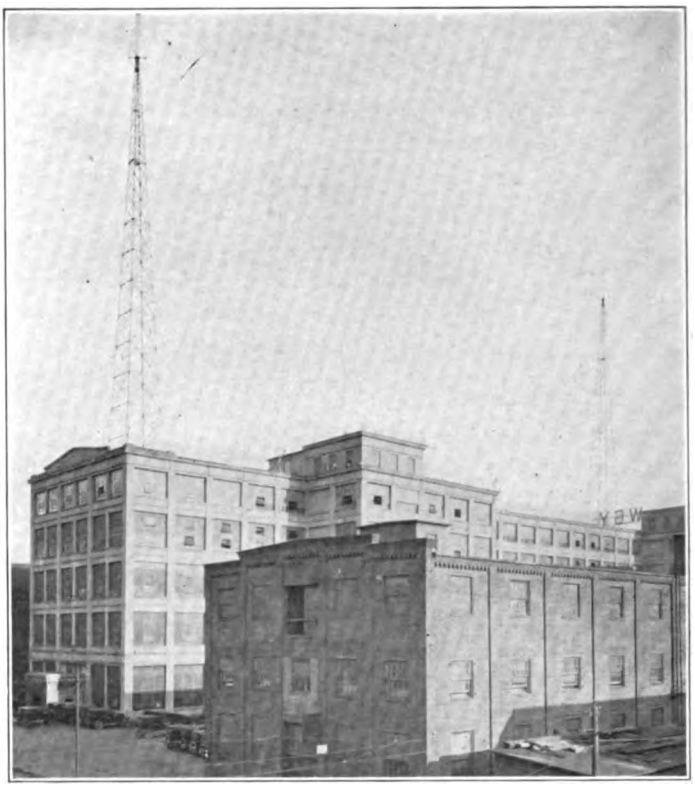

Figure 12—"WGY" Broadcasting Towers

WGY, which is of the multiple tuned type having two tuning points. An extensive counterpoise system is utilized and can be seen in Figure 13, which also shows the outdoor tuning coil. The second multiple tuning coil is located in the power house and serves to transfer power to the antenna. The towers are 185 feet (56 m.) high and placed 352 feet (107 m.) apart. The length of the flat top portion of the antenna system is approximately 200 feet (61 m.).

Rectifier Equipment

The direct current supply for the plate circuits of the tube equipment used for the generation and modulation of the radio

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frequency power is obtained from a battery of kenotron rectifiers. The present equipment with its filter is capable of delivering power at 12,000 volts with a ripple of less than one-tenth of one percent. The schematic circuit diagram is shown in Figure 14 and the actual construction is indicated in Figure 15.

FIGURE 13—Counterpoise and Outdoor Tuning Coil at "WGY"

In this rectifier the delta connected primary is supplied from a 3-phase, 220-volt generator. The high tension windings of the transformer are connected to form two Y's, 180 degrees out of phase. Each Y with its kenotrons is thus a half wave rectifier delivering voltage waves E_1 and E_2 with the odd multiples of the triple harmonic component in the two Y's 180 degrees out of phase and the even components in phase. If the neutral points of the two Y's are connected thru a reactance and the load is connected as shown, the odd multiples of the triple harmonic component will not appear in the rectified voltage wave whereas the even harmonic components will appear. The voltage across the reactor or interphase transformer is the sum of the absolute values of the odd multiple of the triple harmonic frequency

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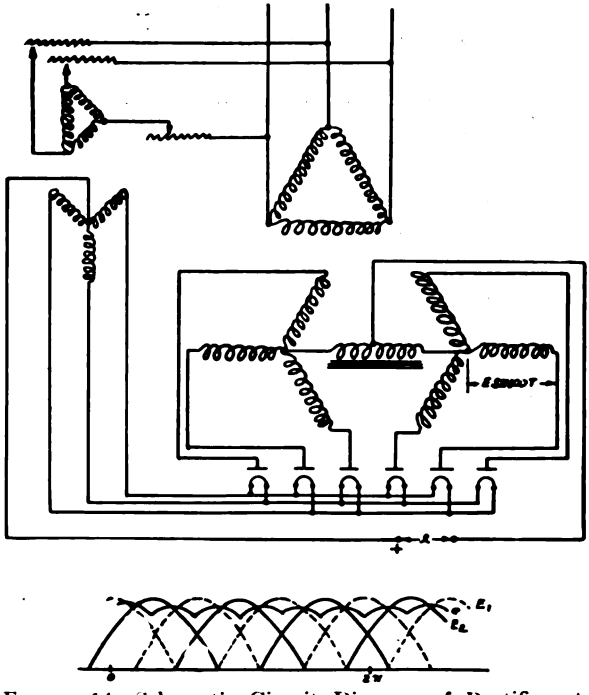

FIGURE 14—Schematic Circuit Diagram of Rectifier at "WGY"

voltage due to each Y. The current due to this voltage is inter-phase transformer magnetizing current, and circulates thru the kenotrons and transformer windings without appearing in the load.

The current waves drawn thru each kenotron are nearly square, lasting for one-third of the cycle. Since there are two high tension windings per phase passing current in opposite directions, the primary current wave is symmetrical and contains no even harmonics. The direct current component of current delivered by each of the two Y's is one-half of the total direct current, so that each tube is required to pass only one-half the maximum value of current required per tube in the ordinary three-phase full-wave rectifier. The tube equipment consists of six UV-218 kenotrons, one of which is shown in Figure 16.

OSCILLATOR AND MODULATOR UNITS

The oscillator circuit is shown schematically in Figure 17. This utilizes a tank circuit loosely coupled to the antenna so that the frequency is determined chiefly by the constants of the

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tank or dummy circuit. The oscillator utilizes one UV-208 tube (Figure 18), operating at reduced output. The complete oscillator and modulator assembly is shown in Figure 19.

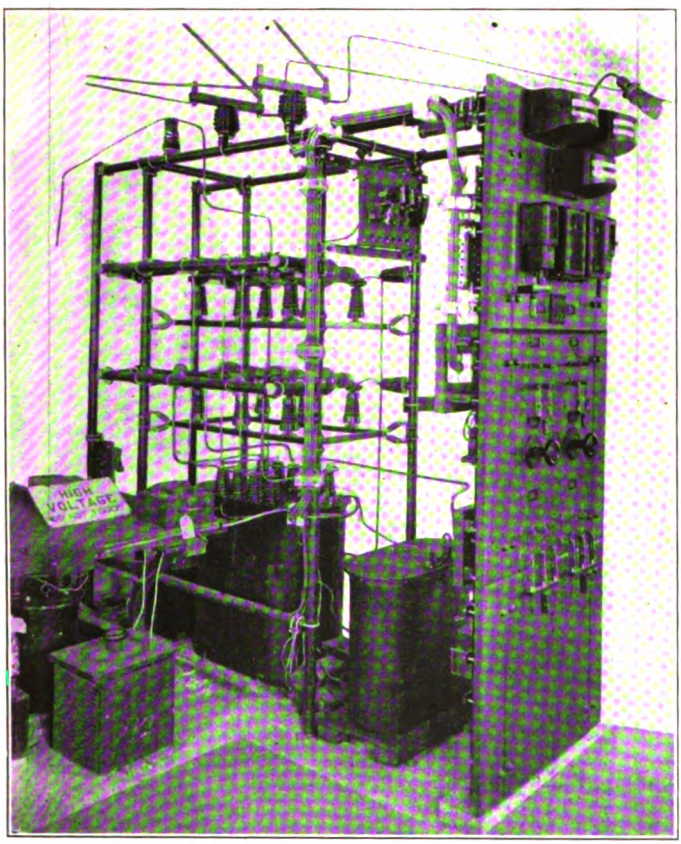

FIGURE 15—Kenotron Rectifier

The modulator employs five UV-206 tubes (Figure 20). The modulating system is that commonly known as the plate method of modulation. The modulation unit also includes an amplifier known as the 4th stage of amplification. This amplifier consists of two units:—a push-pull and a reactance coupled amplifier. Either unit may be used, depending upon operating conditions. Both units use UV-204 tubes at a plate potential of 2,000 volts.

In addition to the apparatus mentioned, the power house contains the necessary generators and batteries together with an oscillograph, power controls, and auxiliary switches.

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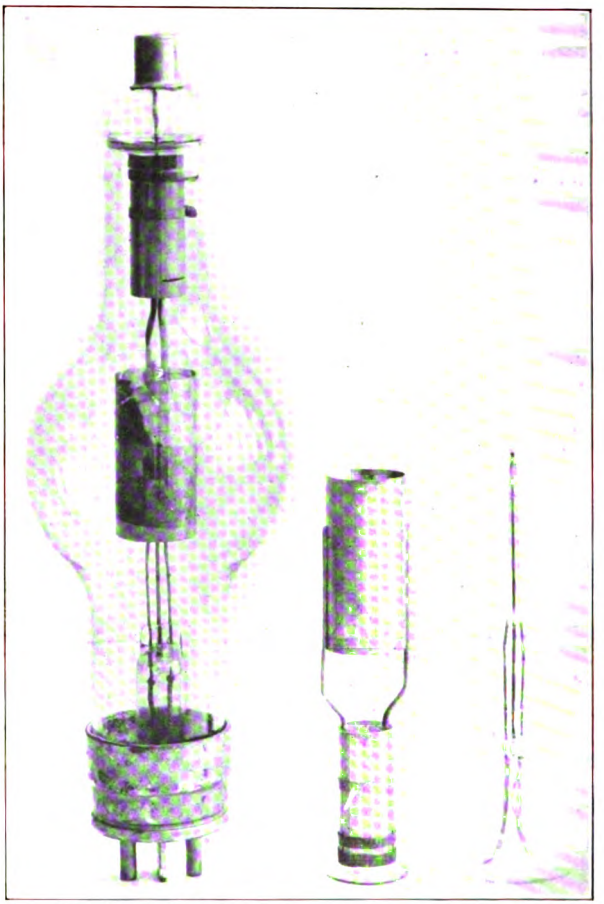

FIGURE 16—Type UV-218 Kenotron (View Showing Electrodes)

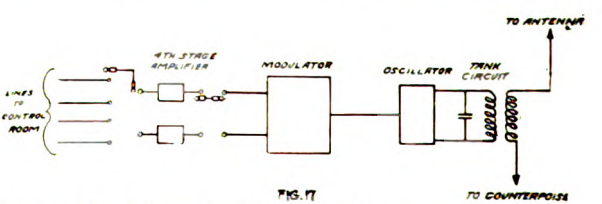

FIGURE 17—Schematic Diagram of Power House Circuits

CONTROL ROOM

In order to understand the function of the control room attention is called to Figure 21 which shows the amplification system. Numbers 1 to 10 indicate first-stage or microphone amplifiers. The microphone circuits from both the main and auxiliary studios

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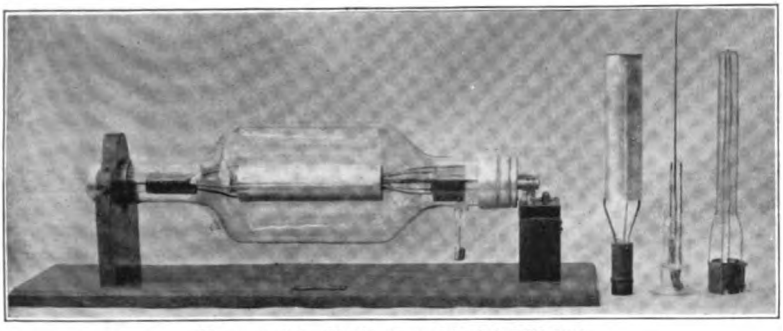

FIGURE 18—Radiotron Model UV-208

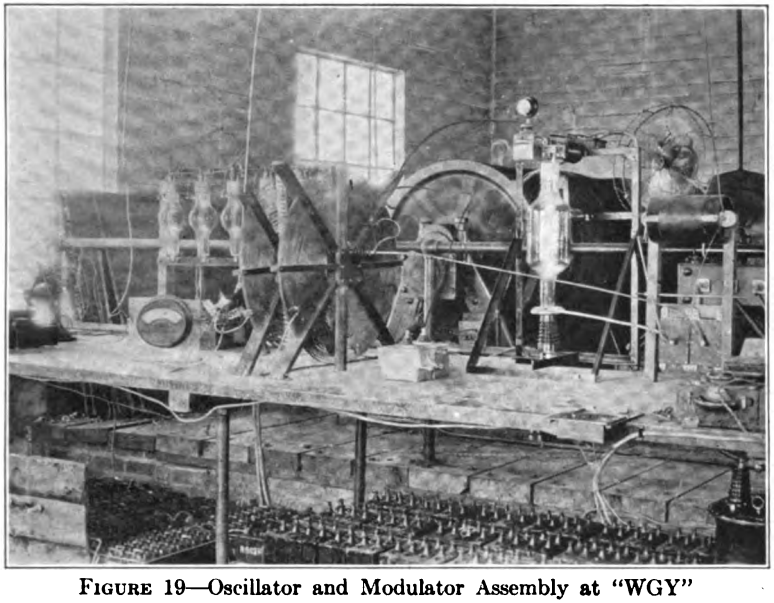

FIGURE 19—Oscillator and Modulator Assembly at "WGY"

terminate in jacks. Four different types of first-stage amplifiers are provided and are selected according to the pick-up device used. In all cases UV-202 tubes (Figure 22) are used operating at a plate potential of from 350 to 400 volts depending upon the type of circuit. The circuits for first-stage amplifiers are shown in Figures 23 to 26, inclusive. Each first-stage amplifier has its own output control, filament control, and listening-in jack. An assembly of one group of amplifiers is shown in Figure 27. Certain amplifiers are assigned to various classes of service, for example, each studio has its own announcing amplifier. In addition some of these amplifiers are used exclusively for broadcasting from places other than the studio.

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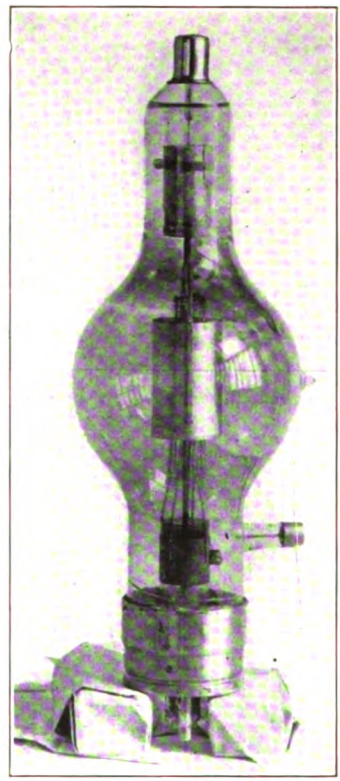

FIGURE 20—Model UV-206 Radiotron

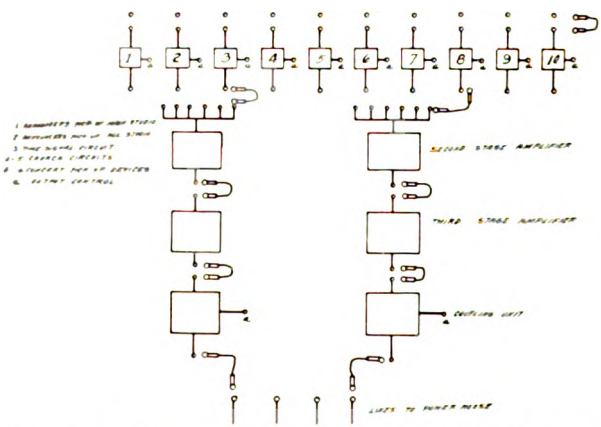

FIGURE 21—Schematic Diagram of Control Room Circuits

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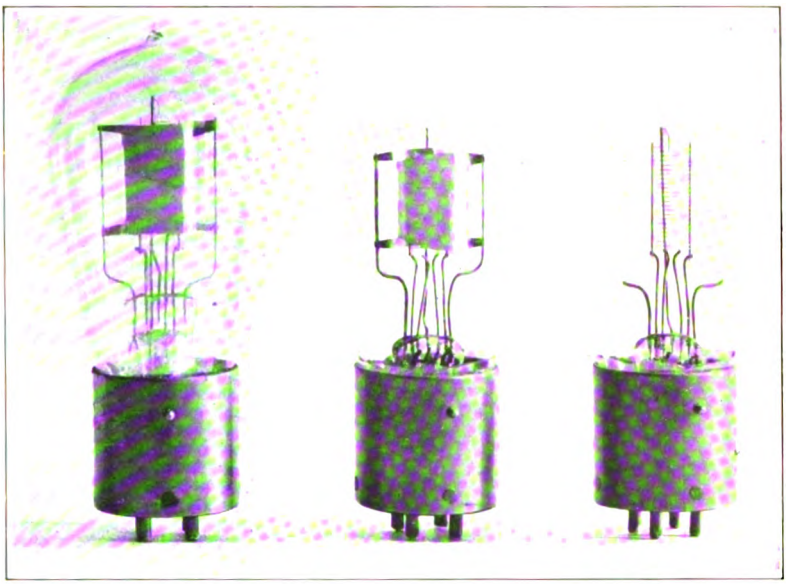

FIGURE 22—5 Watt Transmitting Radiotron Type UV-202

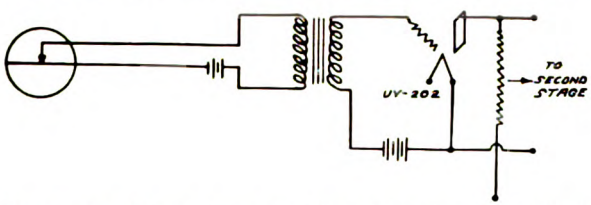

FIGURE 23—Microphone and First Stage Amplifier (Single Button)

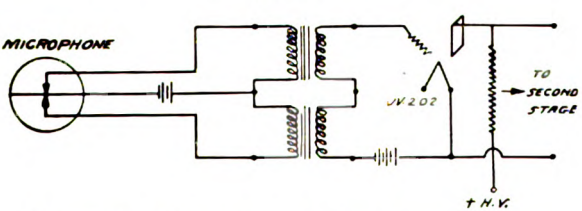

FIGURE 24—Microphone and First Stage Amplifier (Double Button)

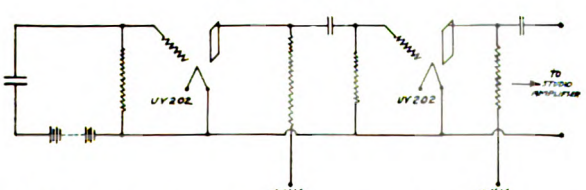

FIGURE 25—Condenser Transmitter and Associated Circuits

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The output circuits of the first-stage amplifiers may be plugged into either one of two second-stage amplifiers. The input circuit of the second stage units includes a number of jacks connected in multiple, thus permitting a number of first-stage amplifiers to be plugged into one second-stage unit. The out-

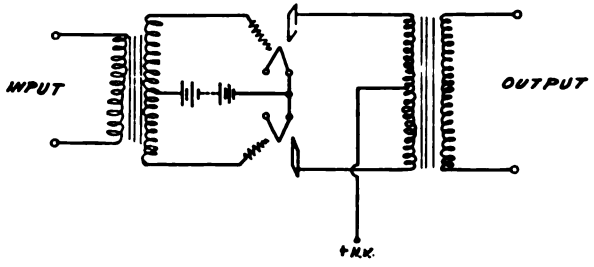

FIGURE 26—Push-Pull Amplifier

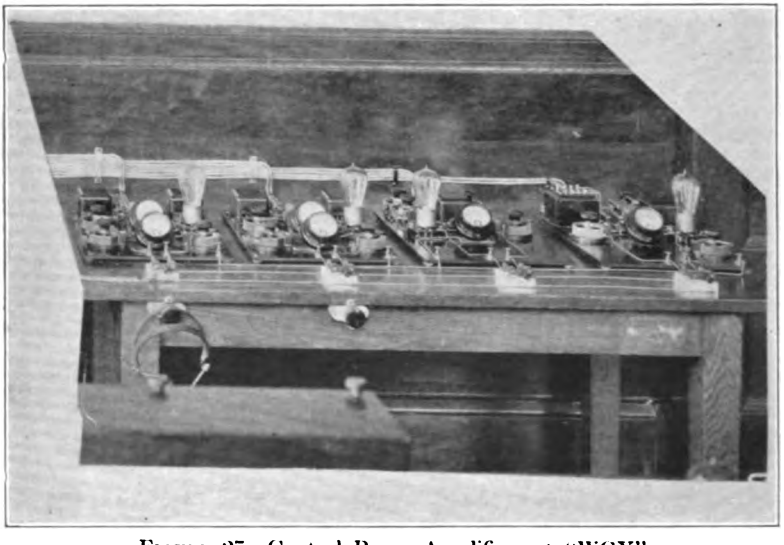

FIGURE 27—Control Room Amplifiers at "WGY"

put of the second-stage amplifier may be plugged into either of two third-stage amplifiers. Both second and third-stage units use one UV-203 tube operated at a plate potential of 600 volts. The circuit diagram of a second-stage amplifier is shown in Figure 28 and that of a third-stage amplifier in Figure 29. Both types of amplifiers use one UV-203 tube operating at a plate potential of 600 volts. Figure 30 shows the assembly of a group of second and third-stage amplifiers with their control equipment.

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The output of the third-stage amplifier is plugged into either of two filter units indicated in Figure 21 as coupling units. The lines to the power house may be plugged into the particular coupling unit in use.

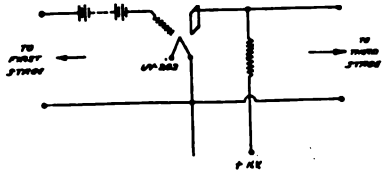

FIGURE 28—Second Stage Amplifier

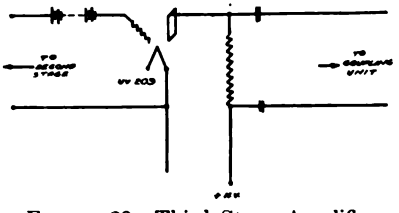

FIGURE 29—Third Stage Amplifier

The input and output jacks of all amplifying equipments are located on the control board shown in Figure 31. The lamps at the top of this switchboard are part of the signaling system.

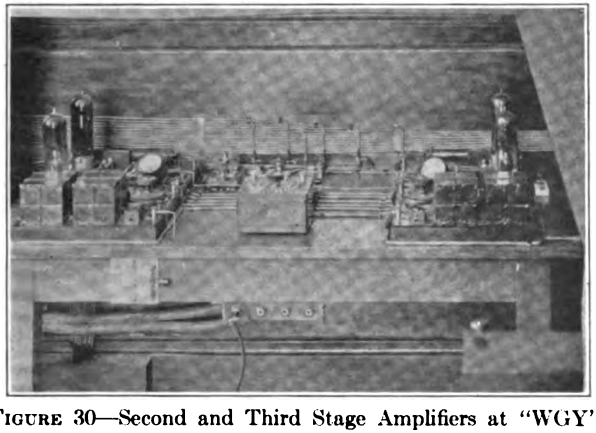

FIGURE 30—Second and Third Stage Amplifiers at "WGY"

Power for the filaments of all amplifiers is obtained from storage batteries. The plate supply may be obtained either from a direct current generator or storage batteries. All power supplies are in duplicate usually by providing both a battery and a generator. The battery equipment is illustrated in Figure 32.

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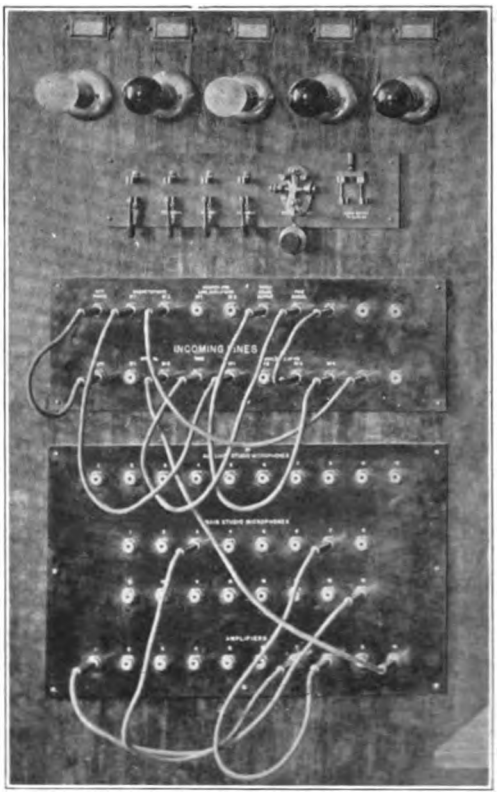

FIGURE 31—Control Board at "WGY"

PICK-UP DEVICES

The pick-up device is one of the most important units of a station since it is depended upon faithfully to transform the efforts of the artist into a form of energy that can be used by the balance of the equipment. This unit is now receiving, and will in the future receive, an increasing amount of attention. While there are a considerable number of pick-up devices in use they may, in general, be divided into four classes:

1. Carbon transmitters.
2. Magnetic transmitters.
3. Condenser transmitters.
4. Special types.

Two types of microphones in the first class are available and are known as single and double-button microphones (Figure 33). Both types have been used considerably at WGY with very fair results.

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The magnetic type of pick-up device as used at WGY not only eliminates some disadvantages of the carbon type but provides a means whereby individual control of certain instruments may be readily accomplished. This is particularly true in the case of the piano. Figure 34 shows the mounting of two pick-up devices on the piano. In this device, the vibrations of the

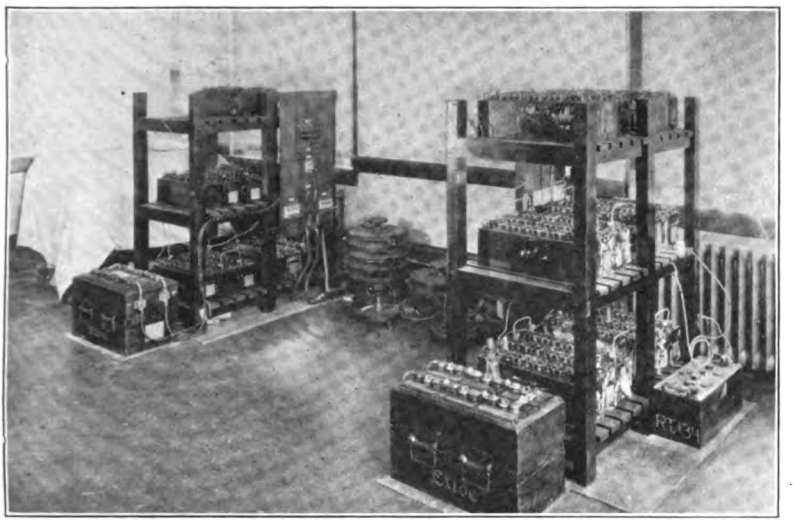

FIGURE 32—Battery Racks Control Room Broadcasting Station, "WGY"

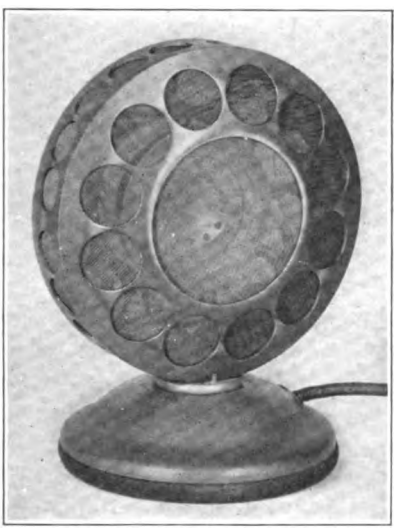

FIGURE 33—Double Button Microphone

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sounding board are transmitted to a rotatable coil. This coil which is placed in a strong magnetic field has induced in it potentials which are impressed on the grid of a special first-stage amplifier.

FIGURE 34—Piano Pick-up Device, "WGY" Broadcasting Station

When this device is used, individual control of a vocal selection and the accompaniment is readily accomplished since the vocal selection would be taken care of by a condenser transmitter or carbon microphone.

A modification of the magnetic transmitter as used for the piano has been applied to phonograph reproduction (Figure 35). This transmitter together with a suitable filter has proved quite satisfactory.

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One type of condenser transmitter is shown in Figure 36. This pick-up device is probably one of the best types for use in the studio, but is somewhat more difficult to apply outside of the station. The general system employed is either to mount the

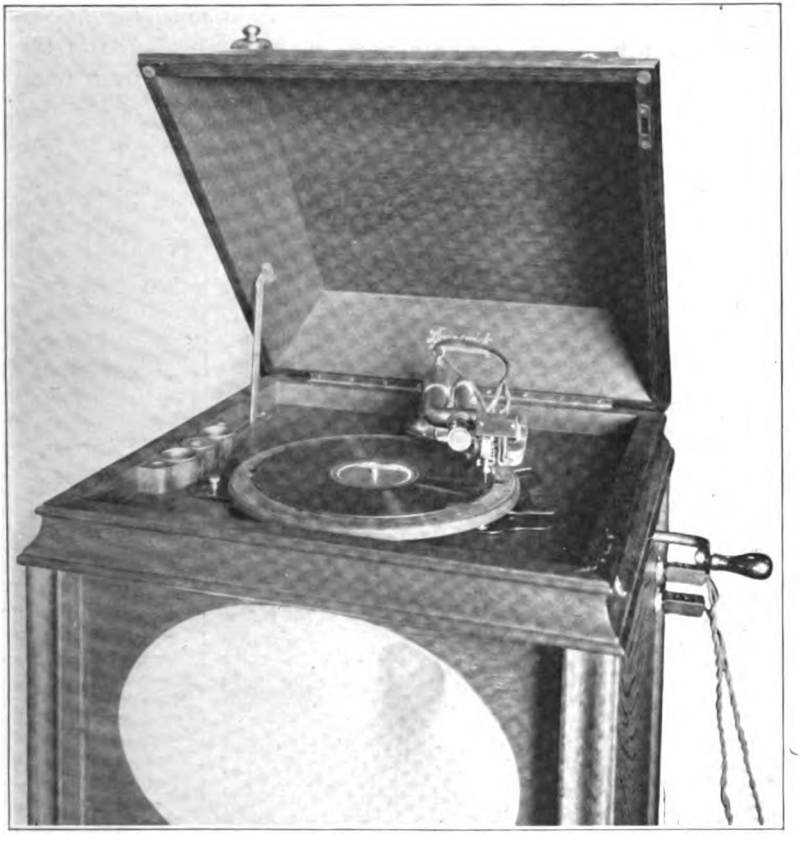

FIGURE 35—Phonograph Pick-up Device, "WGY" Broadcasting Station

microphone on a cabinet containing at least the first amplifier or to locate the unit near the end of the studio so that the amplifiers may be located in the control room. The condenser microphone requires from one to two additional stages of amplification and operates with a potential of 500 volts between plates.

A new type of pick-up device called the Pallophotophone has been used for several types of service.

This device (Figure 37) is dependent for its operation upon the variation of a beam of light. This light is made to fluctuate on and off a light-sensitive cell, the increase or decrease of light

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causing a corresponding change in the flow of current thru the circuit in which the cell is connected. Amplification is obtained in the ordinary way by means of tubes.

The two main features upon which the remarkable quality obtained with the device depends are: (1) the special design of the vibrating system, which is extremely light and responds to vibrations even above the audible range, the amplitude of the mirror movement being many times that of the diafram upon which the sound waves impinge, and (2) the absence of that lag in the operation of the special light cell used, which is so pronounced in the ordinary selenium cell.

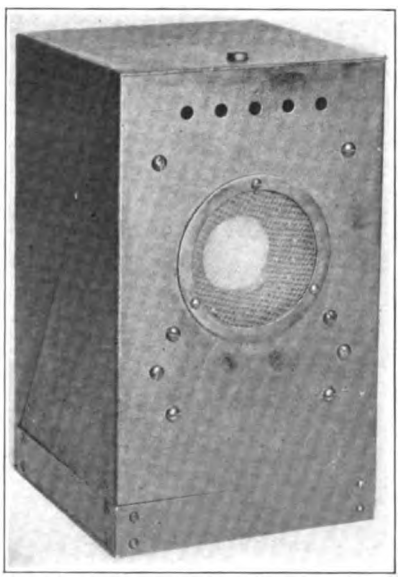

FIGURE 36—Condenser Transmitter

This device as used in the studio is mounted upon a light pedestal that can be easily moved from place to place, all the main controls (Figure 38) being housed in a suitable cabinet and located in the control room.

The Pallophotophone may be used to record and reproduce the voice or music (Figure 39). In this case a sensitized film is made to pass at a uniform speed behind a narrow opening, across which the beam of light before mentioned is made to vibrate. In this way a sort of oscillograph record is photographed upon the film.

In order to reproduce speech or music, light is made to pass

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thru the narrow slot or opening, with which the record was made, onto the light sensitive cell and the photographed record is passed back of the opening at the same speed at which the record was taken. The variations of light passing thru the opening will correspond to the vibrations produced by the original sound waves, and in this way the reproduction will be the same as if a person talked or sang directly into the device.

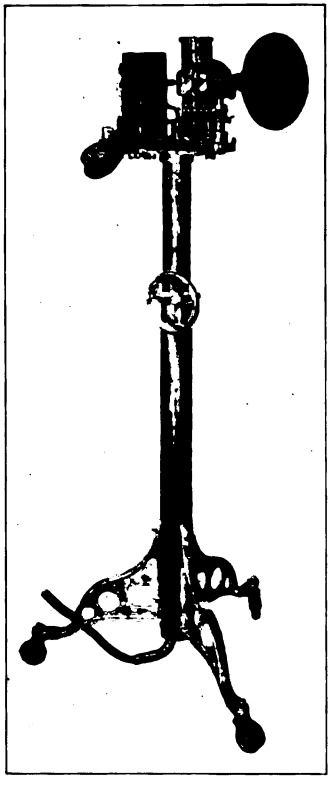

FIGURE 37—Pallophotophone Pick-up Device

In using the reproducer in broadcasting, the electrical impulses are not again converted into sound but are impressed directly on the amplifying system. In this way the distortion that would otherwise be present is eliminated.

TIME SIGNAL RECEIVER

The receiving equipment necessary in order to re-radiate the government time signals is located in the control room. This

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apparatus is shown in Figure 40 and consists of a trap circuit, tuning unit, and amplifiers.

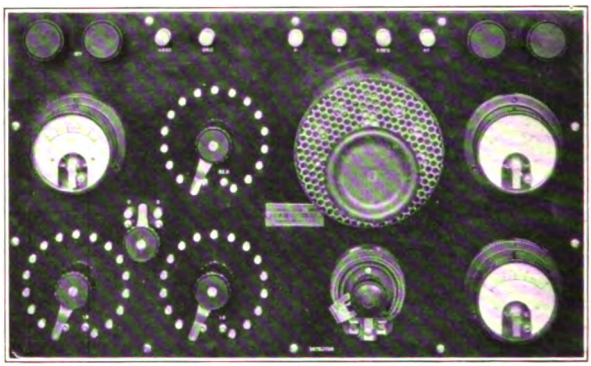

FIGURE 38—Pallophotophone Control Cabinet

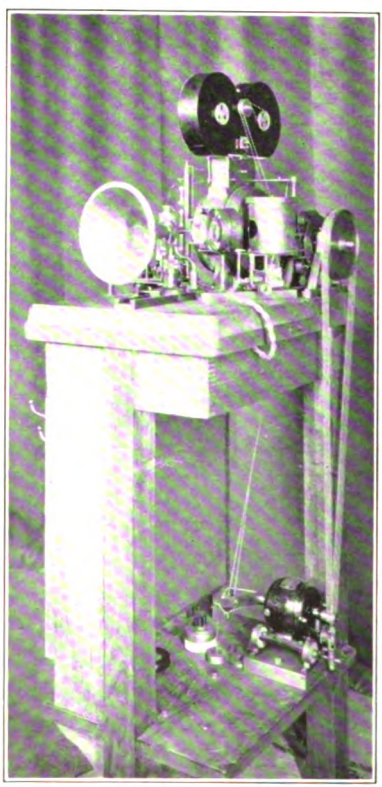

FIGURE 39—Pallophotophone Recorder

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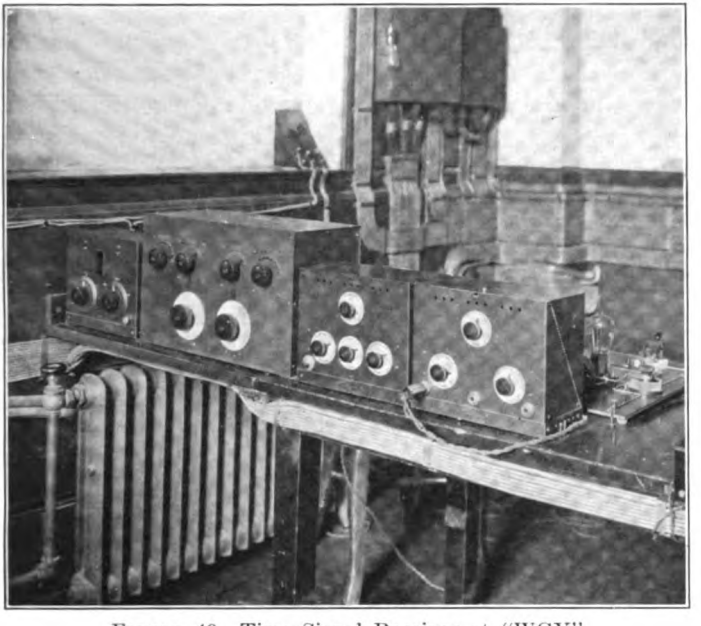

FIGURE 40—Time Signal Receiver at "WGY"

THE STUDIO

A general view of the main studio is shown in Figure 41.

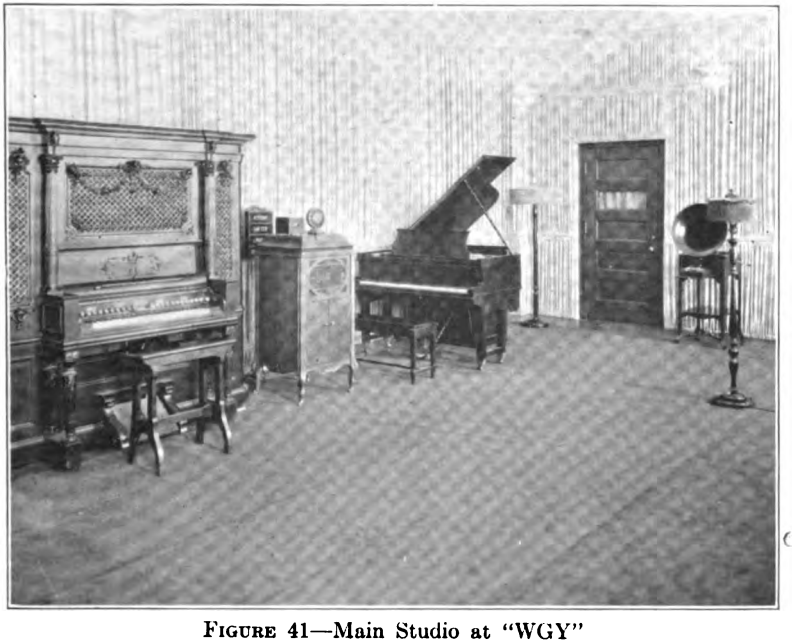

FIGURE 41—Main Studio at "WGY"

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All microphone and control circuits are carried in lead-covered cables laid behind the wall draperies. Connection boxes are arranged near the floor for the microphone outlets. Figure 32 shows the announcer's microphone and control box.

FIGURE 42—Announcer's Microphone and Control Box

The auxiliary studio is of somewhat similar arrangement and differs mainly in that it is considerably smaller. This studio is used chiefly for readings and lectures.

The problem of broadcasting from churches and other places outside of the regular studio has received considerable attention. This is especially necessary when, as in the case of Sunday services, a different church service is broadcast every Sunday. A typical arrangement of pick-up devices is shown in Figure 43 and illustrates the refinement required in order to transmit every part of the service. These pick-ups are controlled by a specially designed unit shown in Figure 44. This control box contains amplifier

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equipment sufficient to compensate for line losses, and so on. Figure 45 illustrates schematically how this equipment is linked with the control room at WGY. With this equipment an operator located at the church switches the various pick-up devices in and out of the circuit according to the requirements of the church service.

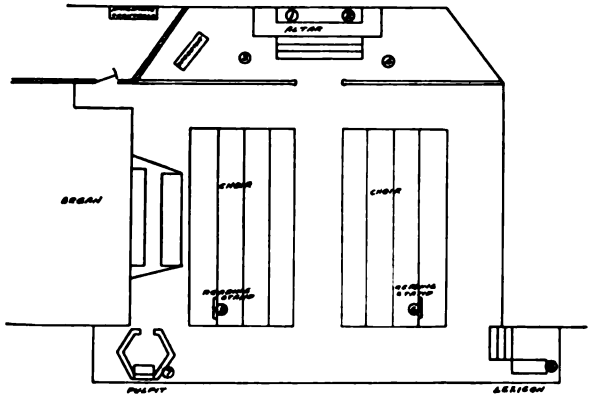

FIGURE 43—Typical Microphone Arrangement for Church Service

When it is required to broadcast from a remote point, it is frequently necessary to add additional amplifiers at this point.

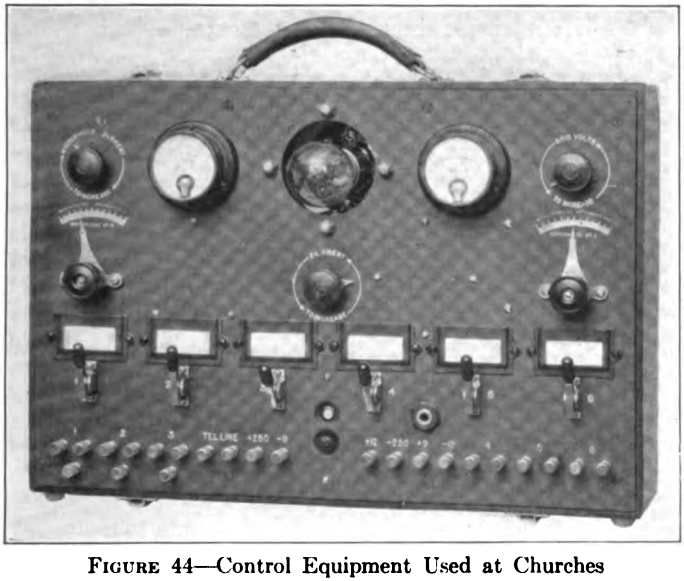

FIGURE 44—Control Equipment Used at Churches

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This, of course, depends upon the electrical characteristic of the lines between the control room and the remote point. Great care is taken in not only obtaining high quality circuits, but in determining the amount of amplification necessary to maintain the speech always above the interference level.

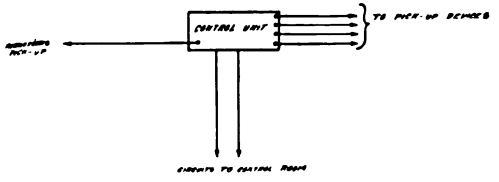

FIGURE 45—Schematic Diagram of Circuits for Broadcasting From Churches

STUDIO OPERATION

A great portion of the success of any broadcasting station depends upon the operation of the studio. The proper placing of the artist and the relation of the various instruments of the orchestra, band or chorus, affects the transmission very materially. Even for the radio play, where a number of pick-up devices may be used or where different pick-up devices are used for the various instruments, the broadcasting may be ruined by improper placement of performers. In cases where a separate pick-up device is used for some instrument such as the piano and where the soloist has an individual pick-up, the location is somewhat simplified, since the relative intensities may be regulated by the individual controls associated with each pick-up device.

The acoustic properties of the studio also have a decided effect on the placement of the pick-up device, especially for music. Obviously the best method of determining the proper location of the microphone is by actually testing with the artist. This not only assures satisfactory operation during the performance but permits a gradual education of the studio manager in locating the artist and microphone to obtain the best results.

Probably the ideal condition would obtain if the pick-up device could be definitely located and the control equipment used to obtain the desired effect. This could be accomplished if, for example, each instrument in an orchestra had a separate pick-up device. In general the individual pick-up idea has worked out very satisfactorily for a limited class of broadcasting. In this class are the radio show, the musical comedy, and similar performances. The radio show in particular requires the use

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of individual pick-up devices. For instance, some casts contain from twelve to fifteen performers, each of whom may act their part. The use of individual microphones together with a knowledge of the play and the general characteristics of each performer permits a selection and grouping of pick-up devices which gives the most realistic results. This, however, does not stop with the performers but includes the various stage effects, such as wind, the ringing of a door or telephone bell, the slamming of a door, the scratching of a match, and so on. These effects are very important in order to assist the imagination of the radio theater-goer.

Obviously the operation of the studio is one of the most important features of a broadcasting station, and is probably destined to be the most important part. While the entire broadcasting equipment may be the best possible, unless the output of the studio is entirely correct, the desired effect on the listener is not obtained.

The grouping for one scene of a play, "The Wolf," is shown is Figure 46 and the grouping for a harp selection in Figure 47.

Operation

In order to understand the duties of the operating personnel and the functioning of the signaling system, it is desirable to trace the operation of the station during the transmission of a program.

The station is manned one-half hour before the program is to start and all clocks checked from a master clock. The two power men on duty measure the insulation of the tie lines to the control room, check all batteries, and operate the entire equipment into an artificial antenna. The senior power man then throws a switch which operates signal lights in the control room and studio indicating to the studio and control men that the power house is ready, but that the power is not on the antenna. So far as the power house is concerned, the set is in operation, and the two operators begin to perform their regular duties. The senior power man supervises the operation of the power equipment, monitors the radio output, and watches the modulation indicators in various parts of the circuit. By means of signal lights he informs the control room whether the modulation should be increased or decreased. In case of emergency he communicates with the control room over the inter-communicating system. The junior power man takes all readings and records them in the log at the beginning of each selection. In case the selection is a

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FIGURE 46—Pick-up Grouping for Scene of a Play

FIGURE 47—Pick-up Grouping for a Harp Selection

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long one, the readings are recorded every ten minutes. This finished the picture insofar as the power house is concerned. These men must keep the station running until directed by the control operator to shut down.

Coming back to the control, we find that the operators have checked all batteries, amplifiers, and pick-up devices, and have connected in those required for the program.

In the studio, we find the announcer and his assistant arranging a group of artists. All artists not performing remain in the reception room where a loud-speaking reproducer permits them to hear the other numbers of the concert.

Assume that the artists are placed and the control room has received a signal to this effect. The senior control man throws a key which, operating contactors in the power house, transfers the set from the artificial to the regular antenna. The radiation from the antenna operates a green signal light in the control room and studio. The announcer throws a small key to "Announce" which, thru contactors, connects the announce microphone and its set of amplifiers, and also lights red warning signals in the studio and control room. While the announcement is being made, the control man has grouped the amplifiers and pick-up devices for the first selection. After the announcement has been made, the announcer throws his key to the "concert" position, automatically disconnecting the announce microphone and connecting in the proper concert amplifiers and pick-up devices.

In the control room, the senior operator controls the grouping of the amplifiers and monitors the radio output. The assistant operator takes all readings for each selection and records them in the log and also checks the output of the amplifiers. A third operator keeps a six-hundred meter log and answers telephone calls. This operator also has control of a 1-kilowatt commercial transmitter adjusted for telegraph operation on 300 or 600 meters. This transmitting equipment is quite similar to the commercial transmitter previously described.

In case the pick-up device has been located incorrectly and the control men cannot compensate by any adjustment of the amplifying equipment, a small electric sign is lighted in the studio. This sign is located where it is not visible to the artist and indicates whether the location is wrong with respect to the soloist or the accompanist. It also indicates the general nature of the trouble. If possible, the studio manager then makes the necessary correction in location.

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Quality

It has been indicated that a broadcasting station is good to just the extent that the output of the pick-up device represents the efforts of the artist. This assumes that the balance of the equipment when actuated by the output of the pick-up device does not introduce distortion. The distorting effects may be due to either the acceptance or suppression of a particular frequency or band of frequencies. For example, a unit might amplify some frequencies considerably better than others thus resulting in accentuating those particular frequencies. Distortion may also result from overloading some unit with the result that while faithful reproduction occurs, so long as an impulse does not exceed a certain amplitude, all impulses having amplitudes in excess of this limiting value are decreased correspondingly.

While these are but a few of the means whereby distortion may be introduced, they indicate the care required to obtain the high quality transmission necessary for a broadcasting equipment. The over-all frequency characteristic of WGY is shown in Figure 48. The dotted line represents the condition that

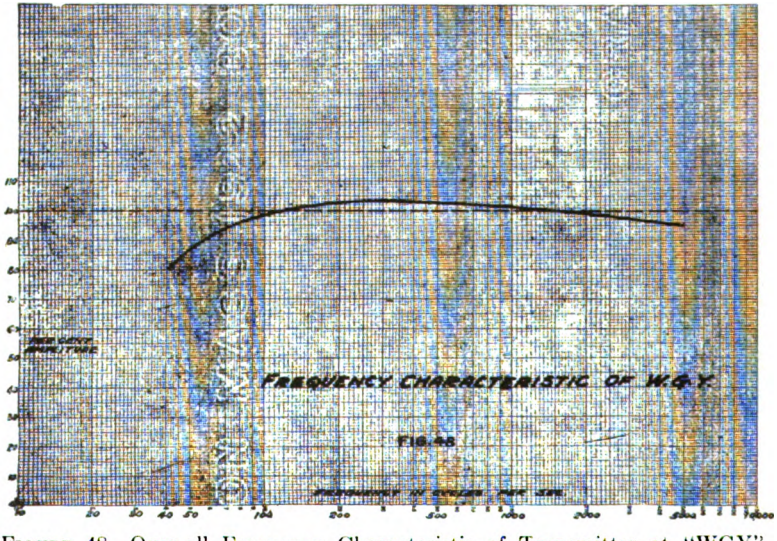

FIGURE 48—Over-all Frequency Characteristic of Transmitter at "WGY"

should exist for theoretically perfect transmission. The solid line indicates the actual frequency characteristic obtained. This characteristic was obtained by substituting a source of power for the pick-up device, hence any distortion due to the pick-up

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is not considered. It should be noted that the essential frequency band (100 to 5,000 cycles) approximates very closely the ideal characteristic.

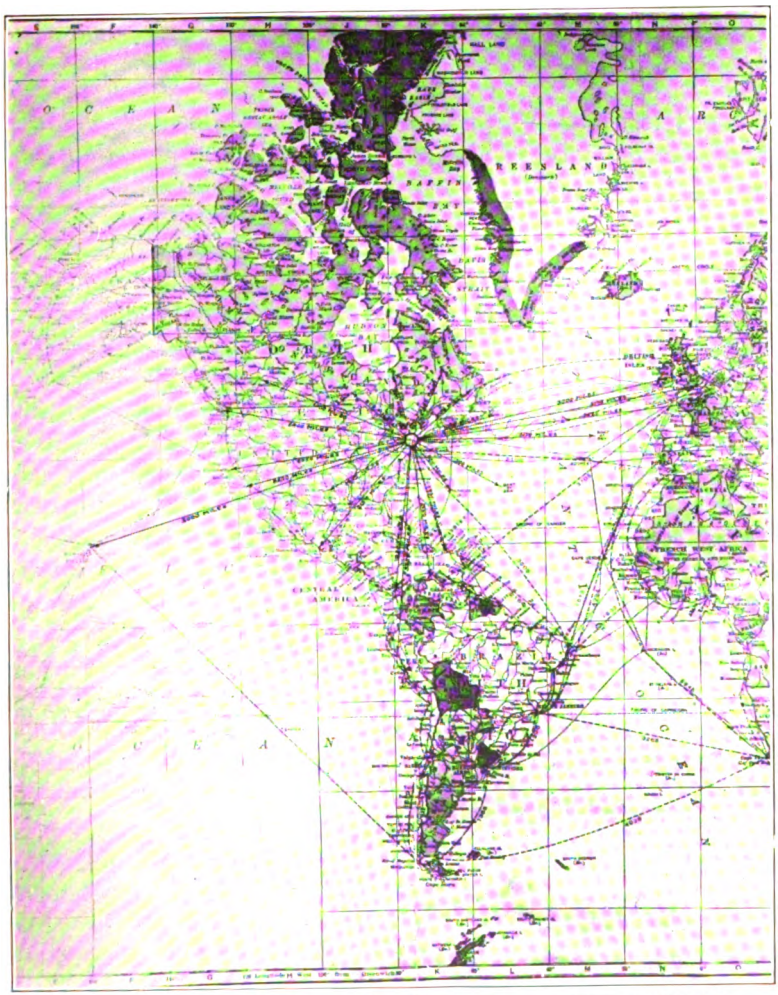

FIGURE 49—Record Ranges of Broadcasting Transmitter at "WGY"

RANGE

Probably the most indefinite factor of a broadcasting station is the range. Not only is the range affected by the usual conditions incident to radio transmission, but in broadcasting it is further complicated by the lack of a common basis of agreement for defining the term. In commercial work the range generally

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indicates the distance over which commercial traffic can be handled satisfactorily. With broadcasting, the reception of even a small portion of a concert, or just sufficient information whereby the station may be identified, immediately establishes a new record.

It is nevertheless interesting to observe the distances that have been obtained. In Figure 49 is shown a map indicating some of the distant points from which reports of WGY have been received. In each case the report of the reception gave sufficient information to prove definitely that the writer had received an appreciable part of at least one program.

Conclusion

The preceding describes in a general way the present-day broadcasting equipment. That great improvements will be made is, of course, obvious. It must be remembered, however, that a considerable investment has already been made in transmitting stations. In addition, the thousands of receiving stations purchased primarily for broadcasting reception necessitate a very careful consideration of the economics of the entire situation before any changes in wave length or method of transmission can be justified if such changes would tend to make this receiving equipment obsolete.

SUMMARY: After a consideration of the points of similarity and of difference of commercial and broadcasting radio telephone transmitters, there are described the pick-up devices, amplifying equipment, transmitters, and control systems of a modern broadcasting station. The factors entering into the operation and performance of such a station are considered.

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INTERFERENCE*

By

Robert H. Marriott

(Radio Aide, United States Navy Yard, Bremerton, Washington)

Interference is an important problem in the theory and practice of radio, and recently it has become a larger and different problem.

Before radio left its shell of laboratory walls, interference was chiefly a theory. For when the experimental transmitter such as the Hertzian oscillator transmitter and the corresponding receiving loop were in the same room, there was usually but one transmitter operating, and the receiver was directional and too insensitive to be disturbed by other electromagnetic fields. But that was more than twenty-five years ago, and radio has changed so greatly now that a condition of lack of interference is chiefly a theory.

When radio first came out of the laboratory, interference was often an encouragement to those who struggled to make stations work. Their coherers responded to static and local electromagnetic fields, producing innumerable combinations of dots that were mistaken for messages. The recognition of this condition caused the coherer sets to be very thoroly screened by iron cases and was one of the causes of the change to the telephone receiver and detector method of reception.

In 1901, there was unintentional and intentional interference between radio stations in New York harbor. This was when the Marconi Company, the American Wireless Telephone and Telegraph Company, and the De Forest Company all tried to report the International Yacht Races at the same time. That was probably the first marked case of radio interference and the first radio interference fight in this country. It was an object lesson that proved the need for avoiding radio interference and interference fights, and caused experiments and development in tuning and in "etheric diplomacy."

*Received by the Editor, January 6, 1923. Presented before the Seattle Section of The Institute of Radio Engineers, January 6, 1923, and before The Institute of Radio Engineers, New York, May 2, 1923.

[1] "United States Radio Development," page 192, Proceedings of The Institute of Radio Engineers, volume 5, number 3.

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Thru the "Era of Development of Demand for Radio Service"[1] ending in about 1911, interference between radio stations grew. Detectors were developed by listening to interference, and transmitter and receiver tuning was developed to avoid interference, and, as a further result, a portion of the law, effective in 1912 (with regulations), was made to prevent interference by regulating radio station wave lengths, decrements, classes of service, locations, and powers.

The uppermost thought at that time was to prevent interference with SOS calls first, and then to prevent interference with commercial and government telegrams. The result was that nearly all wave lengths were given up to commercial and government telegrams. It was soon recognized that the amateur wanted to play with radio, and he was given the 200 meter wave.

Since then it has been shown that the amateur's wave length is something more than a wholesome sport device that keeps him at home after dark. The amateur went in for a large quantity of audion receivers before the commercial companies and government and proved the worth of the audion. One of the amateurs, Mr. Edwin H. Armstrong worked with his audion bulbs and brought out the regenerative circuit, which started the greater strides in radio. The war came and showed that the amateur is a self-educated military radio force available for the army and navy. And he has shown that he has a self-acquired training that is useful to commercial companies. All of which has brought up the importance of amateur radio in comparison with government and commercial radio.

The audion and the regenerative audion developed into radio telephone broadcasting. The broadcasting was what the public wanted and they put in receivers to get it. They put in so many receivers that the number of government, commercial, and amateur receivers became small in comparison.

To-day when the question is asked as to whether radio stations interfere with others or not, the first thought is whether they interfere with broadcasting receivers, because broadcasting receivers have, by their great numbers, become so important a group of radio receivers.

Freedom from interference with distress calls must be considered as of the highest value. The value of commercial messages is proportionate to the price of the messages. The value of government messages probably can be determined. The value of amateur and broadcast receiving probably may be arrived at by estimating how much the owners have invested

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and are investing in radio apparatus. The demand for interference-preventing devices and regulations should be proportionate to the values mentioned.

The government, commercial companies, and amateurs are organizations equipped to say what actually is the value of their receiving. If the value of broadcast receiving can be estimated, the relative value of the other kinds of receiving should be determinable automatically.

An accurate estimate of the public's investment in broadcast receiving apparatus is not possible. But if we wait for accurate estimates, we may endure some years of unnecessary lack of development and interference while we wait. Even if figures could be obtained from manufacturers and retailers, it soon becomes apparent that there are a large number of temporary manufacturers who never advertise, and there are many home-made sets. Odd machine shops mention the drilling of numerous large sheets of bakelite, cabinet makers tell of specially elaborate boxes made for radio sets, and there are stories of expensive receivers that have been built without buying much but vacuum tubes from the radio dealer.

Suppose as a convenient method of calculation that a city of 200,000 population is taken as a basis, and that the running expenses of the radio retailers are estimated by estimating their rents, cost of help, advertising, lost goods, bad accounts, and so on. One radio store may be found that has an expense of $40 per day, one with a $35 expense, another with a $25 expense, another with a $20 expense. Then there may be anything from department stores to laundry offices that are handling radio goods at an extra expense of from $3 to $15 per day. All of those found may total up to $200 per day. If the retailers get one-third of the sale price, the several stores must sell $600 worth of radio apparatus per day to pay their expenses, and the broadcast listeners of that city must be spending over $500 of that per day for apparatus to get broadcast signals.

If it seems strange that the public of a city of 200,000 should spend $500 per day for broadcast receiving, compare that sum with what they spend for printed broadcasts. They probably spend five times that amount for newspapers.

For convenience in figuring, and to be conservative, suppose that 200,000 people in 100 square miles (250 sq. km.), pay $360 per day for their equipment to receive radio broadcast messages. That amounts to $15 per hour or 25 cents per minute. Broadcast material is not available, and the broadcast listeners are not

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near their instruments, except during a few hours per day, therefore the cost per minute is higher than 25 cents during certain hours and less at other times. In sparsely settled country, the value per minute may be relatively higher because the receivers may have to be more expensive to receive from longer distance or the broadcast time may be shorter or broadcast may supply the only rapid news service. On this basis, a price table may be made for different densities of population and different times of the broadcaster's day. The following chart is an example:

VALUE OF TIME TO BROADCAST LISTENERS

VALUE PER MINTUE FROM

Persons in 100 Square Mile Area	7 to 10 P. M.	5 to 7 P. M.	10 to 11 P. M.	11 P. M. to 12	12 to 1 A. M.	1 to 7 A. M.	7 to 8 A. M.	8 A. M. to Noon	12 to 1 P. M.	1 to 5 P. M.
	$	$	$	$	$	$	$	$	$	$
5,000,000	25.00	15.00	10.00	5.00	1.00	0	0.25	3.00	5.00	3.00
1,000,000	5.00	3.00	2.00	1.00	0.15	0	0.05	0.50	1.00	0.50
500,000	2.50	1.50	1.00	0.50	0.10	0	.....	0.25	0.50	0.25
200,000	1.00	0.60	0.40	0.20	0.05	0	.....	0.10	0.20	0.10
100,000	0.50	0.30	0.20	0.10	.....	0	.....	0.15	0.10	0.05
50,000	0.25	0.15	0.10	0.05	.....	0	.....	.....	0.05	.....
25,000	0.15	0.10	0.05	.....	.....	0	.....	.....	.....	.....
10,000	0.05	0.03	0.01	.....	.....	0	.....	.....	.....	.....
5,000	0.05	0.01	.....	.....	.....	0	.....	.....	.....	.....

Such a table is useful in considering radio problems of the present time, for example:

A telegram-handling radio station doing a business of $25 per day or 2 cents per minute cannot be expected to survive if if interferes during the period when the broadcast listeners' time is worth many times that amount.

OBSERVED AND REPORTED INTERFERENCE

To find out what is interfering with the public, it is necessary to communicate more or less directly with the public. This was done particularly in Seattle, Washington, by making observations and inquiries, by giving out typewritten questionaires, and thru the printed columns and radiophone broadcasts of the Seattle "Post-Intelligencer."

On Sunday, November 12, 1922, the Seattle "Post-Intelligencer," which has a Sunday circulation of about 140,000, printed an article which was preceded and followed for several days by broadcasting. The wording of the article and broadcasts was about as follows:

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"What Interferes With Receiving The Post-Intelligencer Broadcast

"The Post-Intelligencer and R. H. Marriott, Naval Radio Aide are trying to find out what are the worst sources of interference with the receiving of the Post-Intelligencer broadcasts. The purpose is to find ways of reducing or eliminating these interferences.

"Following is a list of interferences which have been noted. Please put a number "one" beside the interference that bothers you most and a number "two" beside the next worst interference, and so on thru the list. Also please write any additional interferences or remarks, and your name and address on a piece of paper and attach it to the marked clipping and mail them to the Radio Editor of the Post-Intelligencer. The address of the place where you receive the broadcasts is the one which will aid us in finding the zones of different kinds of interferences."

Sources of Interference

Seattle Radio Station, KPE.
Navy Radio Station at Seattle, NVL.
Navy Spark Station at Keyport.
Navy Arc Station at Keyport.
.....Station at.....
Amateur Spark Station at.....
Amateur C. W. Station at.....
Broadcast Station at.....
Leaky insulators on high voltage power line.
Hum from light circuits.
Electric Elevators.
Street Cars.
Milwaukee Electric Trains.
Telephone Ringing Circuits.
Wire Telegraph Lines.
Factory Motors.
Regenerative receivers belonging to neighbors.
Annunciator systems.
Neighbors tuning, or connecting and disconnecting their receivers.
Switching lights on and off.
Static.

These reports or copies of them will be turned over to Mr. Marriott. Mr. Marriott as Naval Radio Aide, a director of THE INSTITUTE OF RADIO ENGINEERS, and a member of several engineering and scientific societies, is in a position to co-operate with you thru the "Post-Intelligencer" for the reduction of interference.

As some interference can be reduced or eliminated at the receiver, it will be desirable for you to include a brief statement or sketch of the kind of receiver and antenna you have and how loudly you get the Post-Intelligencer."

Seattle radio station KPE apparently took first place as a producer of interference for broadcast listeners and amateurs.

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It is located at Pier Number 1, not far from the center of population of Seattle, and is a spark station operated by the Port Warden's office of the city of Seattle. The caustic remarks and more or less specific statements about that station indicated the new condition which may be anticipated because of universal public receiving.

There was a tendency to question the need for such a station, and the wisdom of its location and choice of wave length. There were some specific statements to the effect that the station transmitted unnecessarily, and specific statements that the station frequently called NVL, the Naval station five blocks away, and frequently worked with that station altho both stations have wire telephone connections.

NVL, the Naval spark station located in the L. C. Smith Building, and also near the center of the Seattle population, was not complained of quite so much, yet KPE and NVL were spoken of in much the same terms.

Another indication of the trend of the situation is that it seems the broadcast listeners at first blamed nearly all of their interference on the amateurs, and particularly the interference from KPE and NVL. But now the amateurs have largely changed to continuous wave operation, and have apparently more or less advised the public as to where the actual interference comes from.

With these two stations as they are, and broadcasting as it is, they probably will always interfere with amateurs and broadcast listeners if either of these two stations work any time between 10:30 A.M. and 1:00 A.M., and will cause a maximum of irritation by working between 5:30 P.M. and 11:00 P.M.

The Naval spark station at Keyport, about ten miles (16 km.) from the western waterfront of Seattle, is farther away from all parts of Seattle and operates on longer wave lengths. Only one person mentioned interference from this station. He was an amateur living in the part of Seattle nearest to Keyport.

The Navy arc station at Keyport produced harmonics. These harmonics, when summed up in the usual types of receivers, produce what is called "mush."[2] In special receivers built

[2] "Mush" in Ohio means a mixture of corn meal and water. "Mush" in the Northwest may mean any kind of breakfast food, usually rolled oats. "Mush" in Alaska means something like "move-along." Some people say "Mush" to dogs when they mean "Sit down" or "Lie down." Ohio mush mixed and fried in Pennsylvania with pork scraps produces what is called "Scrapel." "Scrapel" may be a better name than "mush" for scrambled harmonics.—R. H. M.

Mr. Marriott's search for a sufficiently expressive term for harmonic emissions is significant of the seriousness of the problem.—EDITOR.

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for finding them, each harmonic "whistles" or "squeals" like any other continuous wave beat.

The Keyport arc harmonics damaged the quality of local broadcast receiving in some parts of Seattle and interfered materially with long distance broadcast and amateur receiving.

From November 22, 1922 to November 28th, an experimental harmonic reducing circuit was put into operation at Keyport while handling the regular station traffic. A special schedule, sending "V's" was operated on Sunday, November 26th, from 10:30 A.M. to 11:00 A.M., and from 2:30 P.M. to 3:00 P.M. The public was advised of this thru the columns and broadcasts of the "Post-Intelligencer," and volunteer observers were notified by mail asking all to report. The reports were to the effect that the harmonics did not interfere, altho some harmonics could be found with sensitive receivers. These reports agreed with our findings at three observing stations on three kinds of antennas, nine miles (14 km.) from Keyport.

To avoid the crowded arrangement at Keyport, an upper floor was built, and the experimental apparatus more substantially rebuilt and operated on regular traffic from De cember 5th to 13th. This apparently reduced the harmonics still further.

Another experimental arrangement was put into operation on the night of December 14th. This arrangement apparently gives still greater efficiency and practically eliminates twenty-five or more of the objectionable harmonics. Apparently the Keyport station no longer interfered with the reception of any wave lengths below 1,000 meters when the receiving station was located nine miles (14 km.) or more from Keyport. We are now working on a revision of this circuit. It is possible that the harmonics may be eliminated above 1,000 meters, leaving only the 5,400 meter fundamental.

When changes are made in experimental harmonic reducers, another ordinary arc is used at Keyport and this brings in reports of harmonic interference. Lack of space and limited appropriations may make it necessary to use this ordinary arc at times when the arc equipped with harmonic reducing circuits requires repairs.

Obtaining information thru the printed and spoken broadcasts of the "Post-Intelligencer" indicated how far-reaching such broadcasts are. A man living about seven hundred miles (1,120 km.) from Seattle, in the United States, reported that receiving

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local broadcasts was interfered with and long distance broadcasts eliminated when an arc station in his vicinity was operated.

The amateur spark stations have been changing to continuous waves stations. The amateurs get together. They form clubs and quarrel, and form new clubs. There must have been fifteen such clubs in a series in Seattle in the last seven years. But they keep on getting together and their average performance creates co-operation which differs from that of any other class of radio users.

The continuous wave and interrupted continuous wave amateur stations seem to be a decided improvement over the spark stations. However, some of them produce energy on such wave lengths as 400 meters and interfere with broadcast listeners. And dot-dash c. w. (continuous wave), or modulated c. w. or i. c. w. is not c. w.; it is between the spark set and c. w. set in effect, so far as tuning out is concerned. Also the use of partially rectified alternating current for the plate circuit seems to have been the cause of some interference. And the amateur wave length is so close to the broadcasting wave length that a great deal of interference results, especially when the amateur is a close neighbor.

A 5-watt c. w. telephone and telegraph station, about 600 feet (180 m.) from a broadcast receiving station spoiled all broadcast receiving. It came in more loudly with broadcast receiver set to 400 meters than when adjusted to 200 meters.

The broadcast stations in Seattle apparently were well enough scheduled as to time, so that they seldom interfered with one another. They do, of course, prevent receiving distant broadcast stations if such local stations are nearby and on nearly the same wave length.

They, too, were reported for producing harmonics on 180 to 200 meters, which interfered with amateur receiving. It may be mentioned that we had difficulty in some cases in finding harmonics from the Keyport arc station because they were drowned out or broken up by the fundamental and harmonics from a broadcasting station.

Leaking insulators on high voltage power lines produce interference. Fifty to one-hundred-thousand volt overhead wires are not uncommon in this country. Altho the annual rain fall near Seattle is only about thirty-four inches (86 cm.), most of the rain falls slowly and continuously, especially during the winter. The high voltage discharges over the wet insulators in a mild or violent manner depending on the amount of water on them, the

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voltage, and the size and quality of the insulators. Similar buzzes or crashing sounds can be heard in the broadcast receivers. When a 60,000 volt line is within two hundred feet (60 m.), it may sometimes render unintelligible a broadcast from a 50-watt station located ten miles (16 km.) away.

The operators of high tension lines use lighting arresters which they charge at certain times each day. One company charges its arresters at about 9:00 P.M., producing three long loud crashes that wipe out part of what is sometimes the best broadcast reception of the day.

The hum from electric light circuits is annoying in many cases where the house wiring is not in iron conduit, and particularly where the two sides of the light circuit do not run along together, and thus make a "loop transmitter" with 60-cycle induction. In some cases, the radio receivers or antenna are placed more closely than necessary to the wiring of other circuits.

In one case it was noted that street car circuit interference was very bad when the cars were within a few hundred feet (a hundred meters), and objectionable when they were within a half mile (0.8 km.).

Telephone ringing produces interference in many cases. Switching lights on and off produces clicks. Wire telegraph lines and annunciator systems produce interference at some locations. Motors and generators sometimes create interference.

Neighbors tuning, or connecting and disconnecting receivers have an effect, but usually it is only apparent as a slight change in strength or quality of the received broadcast. X-ray equipments occasionally produce interference over a distance of from a few hundred feet (about 100 meters) to a mile (1.6 km.) or more.

Regenerative receivers belonging to neighbors are usually close-by transmitters that cause a great deal of interference. Sometimes, when they are of the so-called three circuit type (three separate windings), they do not transmit so much. When they use a radio frequency amplifier ahead of the regenerative circuits, they may not transmit interference. In some cases, when the neighbors use one or two radio frequency amplifiers and not the usual regenerative arrangement, the radio amplifiers regenerate and transmit some interference. Careful receiving operators, who use the receiver in a regenerating condition just long enough to pick up the whistle of the broadcasting station they are after, sometimes cause considerable interference if they fail to get that station on the first trial.

Static in the vicinity of Seattle is much milder than in other

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parts of the United States. Thunder storms are not so frequent as in other parts of the country. For local broadcasts, static seems to have been a minor interference in Seattle during the summer of 1922. For receiving long distance broadcasts, it interfered quite decidedly at times.

Suggestions for Reducing Interference

Now that a suggested method for measuring the interference to broadcast listeners has been proposed, using the dollar as the unit for measurement, and since various sorts of interference have been outlined, the next step would seem to be to suggest ways and means for reducing the interference. Some reduction has been made while the material for this paper was being gathered, particularly in connection with the arc harmonics from Keyport. This reduction of arc harmonics may be some compensation to the public, and indirectly to the "Post-Intelligencer," for their help in gathering data on the subject.

Human beings have to do with the production of all the interference noted above, except static. Static is not affected by a dollar argument,—it is non-human.

Static, and such interference as fellow humans cannot be persuaded to discontinue, can be decreased and sometimes eliminated at the receiver. Screening, directional antennas, and tuning may be used as fortifications against such interference.

Putting all building circuits in continuous and well grounded iron conduit screens off a large part of the interference from these circuits. Putting all of the receiving apparatus, except the antenna and control handles, in a grounded sheet or screen metal box decreases local disturbances.

An ordinary antenna in combination with a rotatable loop antenna may be used to reduce or eliminate interference from any one direction. This arrangement has been occasionally described in print. It is especially fully discussed by Mr. G. W. Pickard and others in a recent paper.[3] While this paper describes static chiefly on long waves and in connection with its elimination, thereby finding the direction of the static source, it is usable for short waves in cutting out undesired stations and other interferences. The loop alone is useful in cutting out interference. However, to use the loop, usually requires more amplifiers than for an ordinary antenna. For accurate directional work using both antenna and loop, a very small ordinary antenna serves

[3] "Static Elimination by Directional Reception," by G. W. Pickard, Proceedings of The Institute of Radio Engineers, volume 8, number 5.

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best to balance the loop. However, a large ordinary antenna can be used by employing loose coupling when balancing. The balanced arrangement decreases the interference and makes the signals about twice as strong as with the loop alone. By increasing the coupling, the signals can be made about as strong as by using the ordinary antenna alone or even stronger, and the disturbance is usually somewhat weaker than with the antenna alone. If the disturbance is from a source in about the same direction as the source of the desired broadcast, the directional arrangement is of little value. The short waves used at present and lack of space for revolving loops make uni-directional arrangements more or less impractical. However, it is quite possible that longer waves will be used and that future houses will be designed to accommodate larger radio equipment. Using the loop alone in local broadcasts apparently often gives a pleasant reduction of interference. The loop does not pick up so much interference from sources at right angles to it.

Using the ordinary antenna, combined with the loop tuned to over 1,000 meters, for uni-directional effects, at two points simultaneously (Astoria and Bremerton), the triangulation results obtained in 1920 indicated Mt. Rainier as the chief static center in this section. One year's daily observations at Bremerton and observations at a point east of Ketchikan, Alaska, also indicated Mt. Rainier as the chief static center for this locality.

Tuning in the receiving instrument reduces some kinds of interference. Tuning arrangements are repeatedly described in publications. Thus, Mr. Frank Conrad has recently described tuning in a somewhat different manner using a simple single coil and regenerative feed back.[4]

Some of the interference of human origin can be corrected by simply notifying the management of whatever organization is operating the interfering device. The management may not know about it or may not want to make a change without specific complaints on which to base the action. And the actual operator may not be in a position either to correct the situation or tell the management about it. For example, the charging of the lighting arresters by the power company at 9:00 P.M. might be changed to 6:00 A.M. if somebody wrote to the General Manager of the power company.

Harmonics and poor transmission from broadcast stations will probably be eliminated by those broadcasters who find that

[4] "Radio Receiving Equipment," by Frank Conrad, PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS, volume 10, number 6.

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they are succeeding. They will eliminate their weak points to become more successful. Therefore the solution seems to be to encourage the broadcasters that have the natural attributes for success. For example, the newspapers should be one industry that is naturally fitted to succeed because newspapers always have been broadcasters of printed words. They know what the public wants and have facilities to get what the public wants. And their oral broadcasting can augment their printed broadcast and vice versa.

Some of the interference from radio stations can also be corrected by notifying the management. For example, one of the rumors encountered when asking for data on the interference situation, was to the effect that one influential man was having operators copy the traffic sent by the Seattle radio station. If he does that, and the copies and logs show any amount of obviously unnecessary sending on the part of that station, then turning copies over to the mayor or council with an explanation of the obviously unnecessary interference should produce results. It would be beneficial also if such observers would supply the local Radio Inspector of the Department of Commerce with a copy. If the law is not being violated, the Radio Inspector cannot do anything now, for it appears that a great amount of unnecessary interference can exist under the present law and regulations. But if the Department of Commerce has evidence showing the existence of such unnecessary interference, the Department will know what kind of laws to ask from Congress. Furthermore, if the observer were to send a copy of his records and a letter asking for better radio laws to his Senator and Representative, it should help in causing Congress to pay attention to the subject. The more letters and reports of radio interference sent to Congressmen, the sooner they will act. And changes in laws and regulations seem to be of primary importance to reduce interference.

Reports of interference by the Navy may be sent to the Secretary of the Navy at Washington or the Commandant of the Naval District in which the interfering station is located. Interference by a commercial station can be reported to the manager of the operating company. Interference by amateurs can be reported to the amateur or the local amateur club. In all cases, copies should help if sent to the local radio inspector or the Department of Commerce at Washington and to Congressmen at Washington.

By deciding on a standard measure of value for the use of

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the ether, and by providing working charts for zones of population, kinds of service, wave length, and time, it should be possible to make laws and regulations that can be used with the charts to prevent interference.

It appears that telegram handling stations could:

(a) Schedule a considerable portion of their traffic for the time between 1:00 A.M. and 7:00 A.M.

(b) Use stations that are not near a large center of population.

(c) Put their overland business on the wires.

(d) Employ operators who get traffic thru without repeating.

(e) Change spark sets to continuous wave sets.

(f) Eliminate harmonics.

If these things are feasible, they should be required by a new law.

The new law should provide for many things; for example: that a receiving station be a receiving station and not a transmitter of continuous waves as it is when the tickler regenerates into the antenna. And very careful law-making attention is apparently necessary in considering the amateur and broadcast listener.

The amateur and the broadcast listener are neighbors, neighbors in wave lengths and in their homes. When the amateur transmits, he is an undesirable neighbor. One solution would be for somebody to move, but apparently there is no neighborhood that is not occupied by broadcast listeners or amateurs (or soon there will be no such neighborhood).

For one or the other to move to another neighborhood of wave lengths has objectionable features, but it seems to be the most practical thing to do.

There are those who suggest that the amateur should keep still all of the time or at least during broadcast periods. That will not do because amateur operating has proved its value, and the most practical time for the amateur to work is between dark and a healthy bed time hour, which period is also the most practical time for the greatest number of broadcast receivers to listen.

The amateur has proved his worth to the government and to commercial radio, and therefore it seems that the government and commercial interests should give up an ample wave length range into which broadcasting can move.

It seems that quite a number of longer wave lengths should be set apart for broadcasting, so that it will be possible to listen

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to a distant station when local stations are working and so that different kinds of broadcasting can be picked up on different wave lengths. Also provision probably should be made for the possibility that one central high power station may broadcast excellent programs which will be picked up, relayed, and re-broadcasted at numerous points.

December 27, 1922.

SUMMARY: A brief history of the development of interference with radio receiving is outlined. The present change in the interference problems caused by the number of broadcast listeners is discussed. The suggestion is made that each kind of radio service be given a value in dollars and cents as a basis for eliminating interference. Estimates are made, and a charge submitted showing the per minute value of freedom from interference, to broadcast listeners, according to the population and time of day. Various sorts of interference to broadcast listeners are listed and described. Suggestions are offered for eliminating or reducing interference.

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John R. Tolmie: I believe it is argued abroad by manufacturers of quenched gap transmitters that such transmitters when well constructed compare favorably with, or are superior to, tube transmitters. Is it known whether they are advancing such an argument in this country?

Robert H. Marriott: So far as I know, the foreign quenched gap manufacturers are not prominently represented in this country at present. On what do they base their claims?

John R. Tolmie: Part of their argument is that the tube transmitters cause about as much interference as do quenched gap transmitters.

Albert Kalin: Makers of tube transmitters want to get the most out of them at smallest cost, and in doing this they produce arrangements that transmit harmonics and other interferences.

T. M. Libby: Cannot the tube transmitter produce good efficiency without using grid bias and couplings that result in such interference?

Albert Kalin: They can approach a theoretical 50 percent efficiency, but they want a higher efficiency and endeavor to get it by producing sharp pulses in the plate circuit.

Robert H. Marriott: It seems that efficiency as a whole should be based more on lack of interference than it is at present.

John R. Tolmie: Beat receivers cause a great deal of the interference.

Howard F. Mason: So many listeners listening for long distance cause a lot of interference. Broadcasting stations have experimental licenses to be used for testing, and they use those licenses to call up each other over long distances. Then, too, broadcast listeners make their receivers oscillate to pick up those broadcasting stations so that they can listen in and hear what the broadcasting stations say to each other.

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ON SUPER-REGENERATION*

By

E. O. Hulburt

(University of Iowa, Iowa City, Iowa)

The Armstrong super-regenerative circuit consists of the usual regenerative system, obtained by coupling the plate and grid circuits, with the addition of a local variation of relatively low frequency which is impressed either directly or indirectly on the grid. The explanation of the action of this system, set forth clearly by Armstrong,[1] may be given briefly as follows: In the absence of the low frequency variation the circuit would oscillate spontaneously at a radio frequency which is tuned to be either exactly or closely that of the incoming signal. The low frequency variation, however, introduces periodically a negative and a positive resistance into the radio oscillatory circuit and is found either to prevent the radio frequency oscillation entirely or to reduce it to a negligible value. In the presence of a signal the radio oscillation begins when the resistance arrives at a negative value, and during the interval that the resistance is negative builds up rapidly by regenerative action until a relatively great amplitude is attained. It is only prevented from reaching amplitudes sufficient to defeat the action of the circuit by the reversal of sign of the resistance. During the interval that the resistance is positive the radio frequency oscillation is reduced rapidly to zero, and then when the resistance becomes negative once more the amplifying action is repeated.

It has been pointed out by others that the expressions "negative resistance" and "positive resistance" do not perhaps afford a clear idea of the action in the circuit altho their general meaning is unquestionably correct. A more precise description of the action might be obtained by considering that the effect of the low frequency variation is to shift periodically the operating value of the grid potential so that the characteristics of the tube change periodically, at one moment the characteristics being such that the circuit is free to oscillate, corresponding to the negative resistance case, and at another moment being such as to prevent oscillation, corresponding to the positive resistance case.

A simple mathematical analysis brings out some essential

* Received by the Editor, February 21, 1923.

[1] Proceedings of The Institute of Radio Engineers, volume 10, page 244, 1922.

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features of the super-regenerative action.

Let f be the frequency of the signal and of the radio frequency renegerative circuit, and let F be the frequency of the low frequency variation. For simplicity we shall assume that the variable resistance drops sharply to a finite negative value and remains there for an interval of time $1/\beta F$, where β is a number greater than 2. This assumption, of course, is not a statement of the actual case, for in reality the resistance both descends to the negative region and ascends therefrom as a continuous function. However, by the introduction of the multiplying factor β, the rather complicated action which really takes place may be represented in the theoretical way just mentioned. We denote by e_1, the grid voltage caused by the signal at the beginning of the time interval $1/\beta F$. Because of regenerative action, the grid voltage will increase rapidly according to an exponential law, which is the usual expression for this type of cumulative action. We may then write

$$e = e_1 \varepsilon^{kft},$$

where e is the value of the grid voltage at the time t and k is the constant of regeneration. k also contains the factor 2π resulting from defining f as a frequency. The average value E_1 of e over the interval $1/\beta F$ is given by

$$E_1 = \beta F \int_0^{\frac{1}{\beta F}} e_1 \varepsilon^{kft}\, dt = e_1 \frac{\beta F}{kf}\left(\varepsilon^{\frac{kf}{\beta F}} - 1\right). \qquad (1)$$

For a second signal which produces a grid voltage e_2, and which differs from the signal corresponding to e_1 only in intensity, the average value E_2 of the amplified grid voltage is such that

$$E_2 = e_2 \frac{\beta F}{kf}\left(\varepsilon^{\frac{kf}{\beta F}} - 1\right).$$

Then

$$\frac{E_1}{E_2} = \frac{e_1}{e_2}.$$

This shows that the amplification produces no distortion. This is in agreement with observation, for it is known that the super-regenerative system amplifies radio telephone signals without distortion.

The influence of the frequency of the resistance variation also appears from equation (1). Suppose that the same signal is amplified by super-regeneration using resistance variation frequencies F' and F'', which give rise to amplified average grid voltages E' and E'', respectively. Then, if other factors are considered constant in the two cases,

$$\frac{E'}{E''} = \frac{F'}{F''} \frac{\varepsilon^{\frac{kf}{\beta F'}} - 1}{\varepsilon^{\frac{kf}{\beta F''}} - 1}.$$

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Since $k f/\beta F$ is a quantity much greater than unity, for if it were not the super-regenerative circuit would not amplify, this expression reduces approximately to

$$\frac{E'}{E''} = \frac{F'}{F''} \varepsilon^{\frac{kf}{\beta}\left(\frac{1}{F'} - \frac{1}{F''}\right)}. \qquad (2)$$

In the usual detector action the rectified component of the plate current corresponding to an impressed grid voltage is, to a first approximation, directly proportional to the square of the impressed grid voltage. The intensity of the sound heard in the telephones is directly proportional to the square of the rectified plate current. Therefore, the intensity of the sound is directly proportional to the fourth power of the impressed grid voltage. Denoting the sound intensity by I' and I'' for the two cases under consideration we have from (2)

$$\frac{I'}{I''} = \left\{ \frac{F'}{F''} \varepsilon^{\frac{kf}{\beta}\left(\frac{1}{F'} - \frac{1}{F''}\right)} \right\}^4.$$

From this we may expect the intensity of the signal heard in the telephones to increase very rapidly as the frequency of the resistance variation is decreased. A similar argument may be followed out in the case of the signal frequency, and the conclusion reached that, other things being equal, the intensity of the signal heard in the telephones increases in a marked manner as the signal frequency is increased. These conclusions are in accord with qualitative observation.

In spite of the numerous simplifications and variations of Armstrong's super-regenerative circuits which have been published (see, for example, recent numbers of "QST"), the author ventures to draw attention to the circuits of Figures 1 and 2. These systems were found very useful for a laboratory or class demonstration, being simple to assemble and operate and appearing to retain the amplification and selectivity characteristic of the more elaborate super-regenerative systems. The circuit of Figure 1 was the usual radio frequency regenerative receiver circuit with the addition of the low frequency circuit L_4 C_4. The air condensers C_2, C_3, and C_4 were each variable from 20 to 1,000 $\mu\mu$f. The cylindrical coils L_2 and L_3, 17 cm. (6.7 inches) in diameter, each consisted of 22 turns of wire. L_4 was a honeycomb coil of 1,250 turns and of inductance about 0.1 henry. This arrangement was effective in receiving outside signals. The circuit of Figure 2 was a simple oscillatory circuit with the low frequency circuit L_3 C_3 introduced into the filament connection. C_2 and C_3 were air condensers variable from 20 to 1,000 $\mu\mu$f, and the coils L_1 and L_2 were each of 15 turns of wire on a cylindrical

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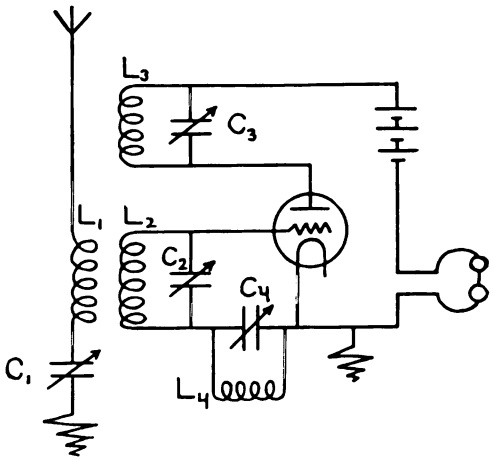

FIGURE 1

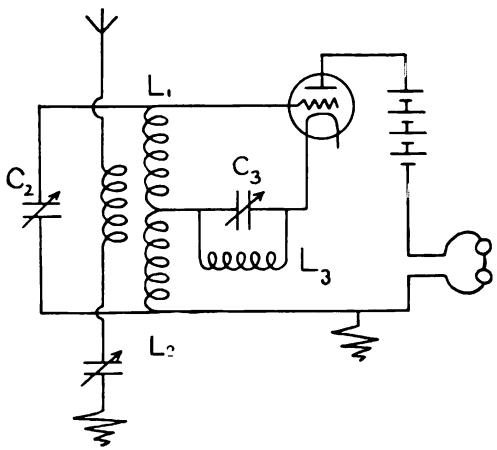

FIGURE 2

form 17 cm. (6.7 inches) in diameter. L_3 was the honeycomb coil of Figure 1. This circuit was interesting rather for its simplicity than for its usefulness as a receiver of signals.

Physical Laboratory,
University of Iowa,
February, 1923

SUMMARY: A simple mathematical analysis of super-regeneration yields conclusions, in accordance with observation, that the super-regenerative system amplifies without distortion and that the amplification increases with increase of signal frequency and with decrease of variation frequency.

Two single tube super-regenerative circuits, interesting because of their simplicity, are described.

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LOOP UNI-DIRECTIONAL RECEIVING CIRCUITS FOR THE DETERMINATION OF THE DIRECTION OF ATMOSPHERIC DISTURBANCES*

By

L. W. Austin

(United States Naval Radio Research Laboratory, Washington, D. C.)

(Communication from the International Union of Scientific Radio Telegraphy)

(American Section)

The swinging frame or loop of 15 turns, 30 ft. (9.15 m.) long, 8 ft. (2.44 m.) high and 4.5 inches (11.9 cm.) spacing is shown in Figure 1, while the circuits used are shown in Figure 2. The

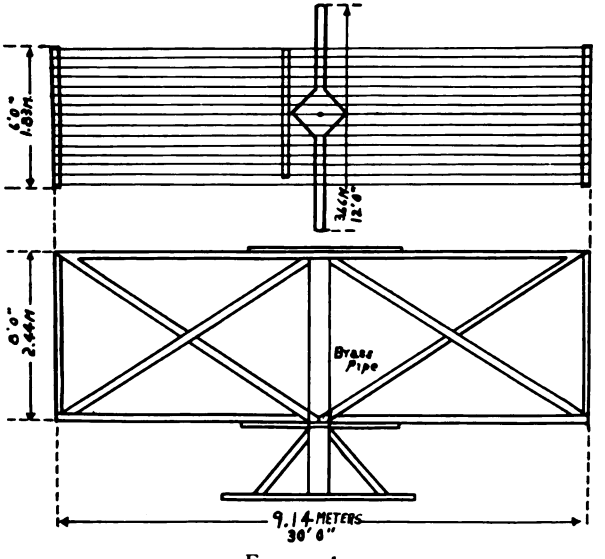

Figure 1

parallel tuned circuit in the antenna simplifies the tuning of long waves on the small antenna and also seems to give a better balance than is obtainable with series tuning. The resistance R_1,

*Received by the Editor, March 30, 1923.

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5,000 to 50,000 ohms, serves to reduce signal strength on the antenna to approximately that of the loop, while R_2, 200 to 1,000 ohms, broadens the tune and enables the coupling to be changed without a too rapid shift of phase, thus rendering a complete balance easy. The balancing antenna used at different stations

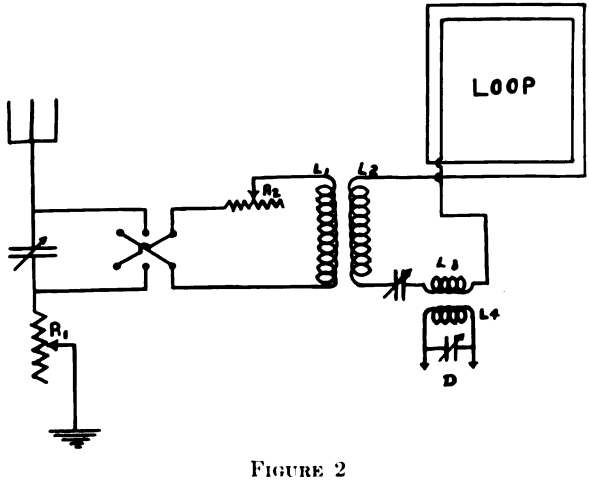

FIGURE 2

varied considerably in size. A single wire 100 ft. (30.4 m.) long and 30 to 50 ft. (9.15 to 15.5 m.) high was found to be satisfactory. The arrangement of coupling between the antenna and loop, as shown in Figure 2, renders the loop uni-directional. With the switch S in one position, signals are received from one side while those from the opposite are cut off, while with the switch reversed, signals are received only from the opposite side. Similar uni-directional combinations can be made between an antenna and a pair of underwater or underground wires, or in fact, between any ordinary antenna and any type of directional collector.

For the determination of static direction, the loop is turned and the coupling L_1 L_2 adjusted so that when the switch S is thrown in one direction the static is a maximum, while with the switch in the opposite direction, it is a minimum. The absolute direction in which the signals are strengthened and weakened with the switch in a certain direction is best determined by observations on a station in a known direction. When this is determined, it is advisable to place a mark on one side of the loop corresponding to a mark on the switch, to indicate the signals from this side of the loop are strengthened with the switch in the marked position. When the general direction of the static

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has been determined as described, the loop is turned approximately at right angles to the indicated direction of the static. Then the switch S is rapidly reversed, the loop at the same time being moved slowly until the position is obtained where the sound of the static on the telephones is of the same intensity with the switch in its two positions. For exact readings the position of the loop expressed in degrees should be observed at which a difference in the intensity of the static is just detectable on each side of the zone of equality. In the mean position between these two points, the loop is exactly at right angles to the static. This method of determining static direction is far more accurate than that of the simple unbalanced loop (radio compass). In fact, good readings can be obtained by the balanced method when no difference at all in intensity can be observed with the simple loop.

If a loop of the size described is not found practicable, a smaller one can be used provided the number of turns is increased so that the product (area of loop)$\times$(number of turns) remains practically constant.

SUMMARY: A balanced loop and vertical antenna method of determining the direction of incoming atmospheric disturbances is described.

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STANDARDS OF CAPACITY PARTICULARLY FOR RADIO FREQUENCY CURRENTS*

By

J. B. Dempster and E. O. Hulburt

(Department of Physics, University of Iowa, Iowa City)

An investigation has been made of condensers which may be used for currents of radio frequency (as well as of other frequencies), and the capacity of which may be calculated with precision from the dimensions. In 1906, the late Lord Rayleigh[1] suggested a method of making and using a condenser which would enable all errors due to end and lead-wire capacities to be avoided. The principle was essentially that of the variable condenser of Maxwell[2] and required an adjustable condenser so constructed that altho its total capacity was unknown the increase in capacity was accurately known.

In the present instance, Rayleigh's suggestion has been adopted with some slight modification for measurements with radio frequency currents. A condenser of two coaxial cylinders was made according to the diagram of Figure 1. The two end pieces A consisted of cylindrical cups of brass about 7 cm. (2.76 in.) in length, each with an interior cup of brass held rigidly and accurately centered in the external cup by means of the insulating ring b and post d of hard rubber. The brass collars a and discs c served to keep the cylinders circular in cross section. The ends A fitted on to the section B which consisted of an interior and exterior cylinder of brass. The cylinders were held in place only by the ends A. The mean inner radius of the outer cylinder was 4.9232 cm. (1.93 in.) and the mean outer radius of the inner cylinder was 4.1326 cm. (1.63 in.). Connection was made to the inner cylinder by means of a brass rod e insulated from the outer cylinder. The capacity of the condenser with section B in place was measured in arbitrary units on the scale of a variable air condenser. Section B was then removed, the ends A were fitted together and the capacity of the condenser, which was composed

* Received by the Editor, May 28, 1923.

[1] "Philosophical Magazine," 12, 97, 1906.

[2] "Electricity and Magnetism," section 127

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only of the ends A, was recorded on the variable condenser. The difference in the two readings was exactly the capacity of section B given by the formula.

$$C = \frac{k\,l}{2\,log_{\epsilon}\,\frac{r_2}{r_1}},$$

where r_2 and r_1 are the radii of the external and internal cylinders, respectively, k is the dielectric constant of the medium, and l is the length of the section. In the present case k was unity, for air was between the condenser plates. Three sections were made to be placed at B, their lengths being 31.560, 15,780, and 7.890 cm. (12.4, 6.2, and 3.1 in.), so that the respective capacities were 100, 50, and 25 micromicrofarads. Any of these, either alone or in combination with the others, could be fitted between the ends A.

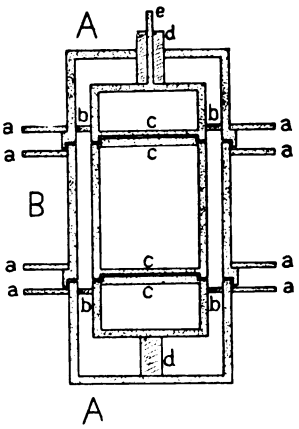

FIGURE 1

No standard condensers were at hand with which these could be compared. Measurements of the capacities by means of resonant circuits supplied with undamped radio frequency current showed that the 100 $\mu\mu$f. section was equal to four times the 25 $\mu\mu$f. section and to twice the 50 $\mu\mu$f. section within the error of observation which was less than 0.2 $\mu\mu$f. Currents of frequencies corresponding to wave-lengths of 600 meters and 300 meters gave the same results. This was considered to be a decisive and complete verification that the absolute values of the capacities of the sections were what they were designed to be and that the condensers could be used with confidence with alternating current measurements. A photograph of the standard condenser is shown in Figure 2.

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Lord Rayleigh recorded no measurements with this type of condenser. We should perhaps remark that a condenser of the form of that of Figure 1, in which the section B was insulated from the ends A was used by Rosa and Dorsey[3] in their determination of the ratio of the electrical units. Such a condenser, however, was of the guard type due to Lord Kelvin, and, therefore, was quite different from the one used here. It would be unsuited to measurements with alternating currents.

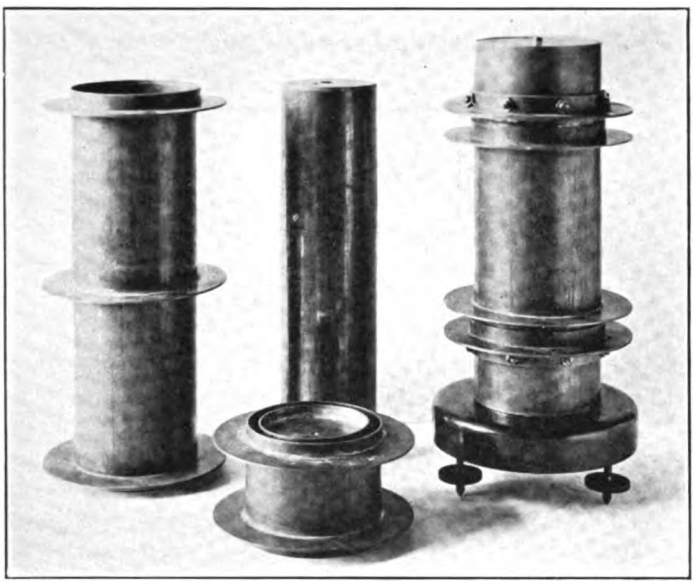

FIGURE 2

A semi-circular plate variable air condenser of forty-three plates was accurately calibrated and was used thereafter as a secondary standard. The dial of this condenser had 100 scale divisions and was turned by a worm-screw which had a head graduated into 100 parts. Measurements showed that each of these parts corresponded to a capacity change of 0.0676 $\mu\mu$f. This condenser was calibrated by means of the circuit of Figure 3. C_1 was the standard condenser of Figure 1, C_2 was the secondary standard, and C_3 was a variable air condenser. Current of frequency about 10^6 was induced in the circuit by coupling L loosely to an electron tube continuous wave generator. The central section B was removed from C_1 so that its capacity was formed

[3] "Bulletin of the Bureau of Standards," 3, 433, 1907.

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only by two end sections A, condenser C_2 was set at a specified reading and the circuit was tuned to resonance by C_3. Section B was inserted into C_1, and C_2 was reduced untll resonance again occurred. The difference in the two readings of C_2 was equal to the capacity of section B. In this manner the secondary standard was calibrated step by step thruout its range. The calibration curve obtained in this way gave only the capacity corresponding to the difference in two scale readings. To fix the absolute value of the capacity corresponding to a scale reading a single direct comparison of the primary and secondary standards was carried out by the method of substitution.

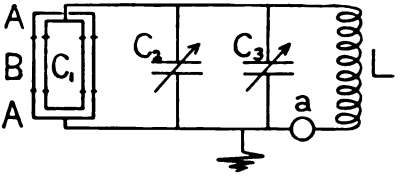

FIGURE 3

The resonance indicating instrument a, Figure 3, consisted of a thermo-couple of resistance 4.5 ohms and a d'Arsonal galvanometer. The galvanometer had a resistance of 121.5 ohms and a sensibility of 6×10^{-8} amperes per millimeter deflection at a scale distance of one meter. A marine type of suspension was used, the period being about one second. This system was quick in action and well adapted to measurements of resonance. Resonance points could be determined with an accuracy of about 0.5 $\mu\mu$f., as may be seen from a typical resonance curve, curve 1, Figure 4. The curve was obtained by plotting the variable capacity in micromicrofarads as abscissas against the current thru the thermo-couple in milliamperes as ordinates. In order to increase the sharpness of the resonance curve, and thereby the accuracy of the capacity measurement, advantage was taken of the fact that the thermo-couple galvanometer system is one in which the deflections are proportional to the square of the current, that is, $i^2=a\,r$ where i is the current, r the deflection, and a a factor of proportionality. The derivative, or sensibility, $d\,i\ d\,r=2\,i\ a$, and is seen to increase in direct proportion to the current i. Therefore, by increasing the coupling between L and the generating circuit to produce a stronger current, a sharper resonance curve was obtained. When stronger currents were used the galvanometer moved off the scale. To avoid this the

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suspending fiber of the galvanometer was twisted slightly to depress the zero point. Curve 2, Figure 4, illustrates the resonance curve in this case, the sharpness of the curve being such as to enable the determination of the resonance point to within 0.2 $\mu\mu$f., or less. Of course there are many methods of determining resonance which are more sensitive than the one just described. These methods are for the most part more difficult of control and do not lend themselves to rapid observations.

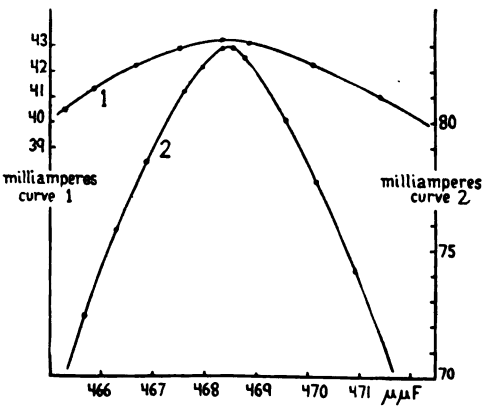

FIGURE 4

It was found that thin metallic discs and small metallic spheres suspended in the air could not in general be used as standards, for their calculated capacities (from the lengths of the radii) and observed capacities were not in agreement, due to unavoidable modification of the electric field caused by the connecting wire. In the case of small spheres the calculated capacities were 4.18, 7.07, and 8.35 $\mu\mu$f. and the measured values were 2.2, 4.2, and 5.0 $\mu\mu$f., respectively, after the observed capacities of the lead-wires had been subtracted. In the case of discs, the calculated capacities were 8.85, 17.7, and 35.4 $\mu\mu$f. When the lead-wire was connected to the centre and normal to the plane of the disc, the observed capacities were 5.7, 13.4, and 32.2 $\mu\mu$f., respectively. If the wire were attached to the edge of the disc the measured capacities became 5.9, 13.6, and 32.8 $\mu\mu$f., respectively.

The capacities of small parallel plate variable condensers were found to be in close agreement with the values calculated from the dimensions and the distance apart of the plates, using the usual formula for the capacity of a parallel plate condenser

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with the edge effect correction. Figure 5 shows a photograph of one of these condensers. Thick brass plates were used, circular in shape, and beveled until the edges were thin.

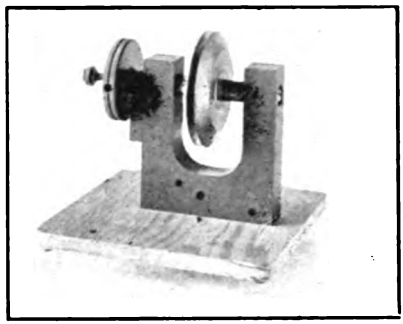

FIGURE 5

We take pleasure in thanking Mr. E. G. Linder for valuable help in making the observations.

Physical Laboratory,
University of Iowa.
May, 1923

SUMMARY: Standards of capacity for use with radio frequency currents, made according to a suggestion of the former Lord Rayleigh, are described. A simple method of increasing the sensitivity of the thermo-couple galvanometer system for indicating resonance is mentioned. Metallic discs and small tpheres were found to be erratic standards, because of unavoidable effects of she connecting wires. The measured capacities of small parallel plate condensers were in agreement with the capacities calculated from the dimensions.

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VACUUM TUBES AS POWER OSCILLATORS

By

D. C. Prince

(Research Laboratory, General Electric Company, Schenectady, N. Y.)

PART II

CHAPTER IV

Partially Tuned Plate Circuit

Altho circuit design where but one tuning is involved has been dealt with in principle, a somewhat more complicated circuit than that used as an example may be analyzed because it throws light not only on the procedure with more complicated circuits, but also on the provision made to avoid parasitic oscillations by providing a partially tuned circuit in addition to the fully tuned circuit which furnishes the main determination of frequency.

Analysis of Semi-tuned Plate Oscillator

The circuit shown in Figure 31 is useful because of the filtering effect of the plate circuit in reducing harmonic radiation. Before discussing the filter action, the oscillating properties require study.

Figure 32 is a vector diagram corresponding to this circuit diagram. To understand this diagram, assume the antenna current I_{L2} flowing in the antenna loading coil L_2. This current induces in the primary inductance L_1 the voltage $I_{L_2} X_M$, due to the coupling. The voltage $I_{L_2} X_M$ has two components, e_r at right angles to $I_{L1} X_{L1}$ and e_x parallel with $I_{L1} X_{L1}$. The former is the power component due to the antenna resistance. The latter represents a wattless interchange between primary and secondary circuits. $I_{L1} X_{L1}$ is the self-induced voltage in L_1. Both $I_{L1} X_{L1}$ and $I_{L2} X_M$ are induced in L_1, so that their sum is impressed upon C_1 and current in C_1 produces the voltage $I_{C1} X_{C1}$. The capacity current I_{C1} leads its voltage 90° while the current in L_1 lags 90° behind its self-induced voltage.

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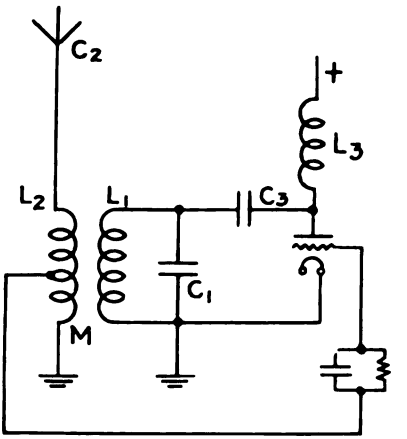

FIGURE 31—Connections of Partially Tuned Plate Circuit

Since the grid is connected to the antenna coil L_2, the grid potential will be at right angles to I_{L2} and the plate potential E_p may be made 180° out of phase by proper choice of C_3, giving voltage $I\,X_{C3}$.

It is apparent that, as drawn, $I_{L1}\,X_{L1}$ and $I_{C1}\,X_{C1}$ are not equal. In other words the primary circuit is not in tune. How-

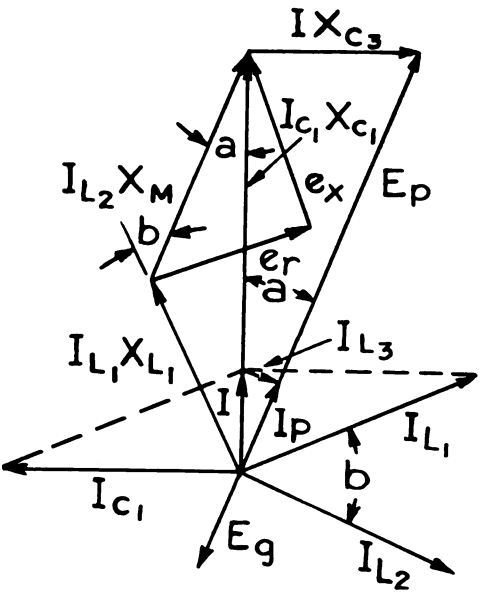

FIGURE 32—Vector Relations in Partially Tuned Plate circuit

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ever, it is also apparent that an increase in $I_{L1} X_{L1}$ must be at the expense of the e_r component of $I_{L2} X_M$, since e_r represents the energy transfer which must be maintained. The angle "b" is determined by the ratio between these two, so that the more nearly tuned the primary circuit the greater the angle "b." If the primary were entirely tuned, "b" would be 90° and it would become entirely impossible to correct this angle by any drop across C_3.

In the other direction, if $X_{C1}/X_{L1}=4$, any second harmonic component in the plate current will be in resonance and a large second harmonic wave may be radiated. If this ratio be greater than 4, a second harmonic current in the antenna will be amplified and continuous second harmonic oscillations might even be built up, provided the wave length were just twice the natural wave length of the antenna. It therefore seems desirable to keep the tuning point of the primary circuit between the fundamental and second harmonic.

Having avoided accentuating harmonics by not making the ratio X_{C1}/X_{L1} too large and the dephasing of the grid by not making this ratio too near unity, the amount of harmonic radiation, for any value of C_1 say, can be determined by plotting out the plate current and making an harmonic analysis of it. This current is then assumed to pass thru C_3 to the primary circuit, and the portion of it which finds its way into the antenna may be calculated directly.

Once C_1 has been made large enough to keep harmonic radiation with inrequired limits, the whole circuit may be calculated exactly by making a quantitative determination from the vector diagram, bearing in mind the values for E_p and E_g from the tube characteristic and that these voltages must be displaced 180° in phase. A sample calculation is attached in which this procedure has been followed.

The coupling required by this circuit is normally quite close, so that it might be expected to be doubly periodic. When a coupled circuit is doubly periodic, the two periods are necessarily further apart than the natural periods of the separate circuits. These periods may, therefore, be well separated. Also the antenna will respond only feebly to oscillations of the higher frequency and, since the grid is driven from the antenna coil, it is easy so to proportion the circuits that the higher frequency oscillation will not be sustained. The greater the separation of tuning points between primary and secondary, the less is the tendency toward double frequency oscillation.

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Appendix to Chapter IV

Calculation of a Partially Tuned Plate Circuit

This circuit is to feed 20 kilowatts at 2,500 meters into a multiple tuned antenna having two downleads. Full power requires 46.5 amperes per downlead. The tube requires alternating potentials of 9,400 volts on the plate and 2,300 volts on the grid. No requirements have to be met regarding harmonics, so the primary volt-amperes will be made equal to approximately 4π times the watts. This results in a value of 0.004 mfd. for C_1.

Tabulating these figures gives:

$\lambda = 2{,}500$ meters $\qquad 2\pi f = 753{,}000$ radians/sec.

$C_1 = 0.004$ mfd. $\qquad \dfrac{1}{2\pi f C_1} = 332$ ohms

$E_p = 9{,}400$ volts $\qquad I_{L2} = 46.5$ amperes

$E_g = 2{,}300$ volts

Power = 20 KW.

The potential across C_1 will be very nearly E_p, so let this value be used. Then

$$I_{C_1} = \frac{9{,}400}{332} = 28.3 \text{ amperes}$$

which may also be taken as the value of I_{L_1} in this case.

Knowing the primary current and power transferred thru the coupling, e_r is given by

$$e_r = \frac{20{,}000}{28.3} = 707 \text{ volts}$$

Now $I_{C_1} X_{C_1}$ is to be built up of the three vectors $I_{L_1} X_{L_1}$, e_r and e_x, and as e_r is only 707 volts and $I_{C_1} X_{C_1}$ is 9,400, we may take $I_{L_1} X_{L_1}$ and e_x to be each equal to 4,700 volts without incurring any error of appreciable magnitude. We then have

$$X_{L_1} = \frac{X_{C_1}}{2} = 166 \text{ ohms}$$

$$L_1 = \frac{166}{753{,}000} = 221 \text{ micro-henrys}$$

$$X_M = \frac{4{,}700 \text{ volts}}{46.5 \text{ amps.}} = 101 \text{ ohms}$$

$$M = \frac{101}{753{,}000} = 134 \text{ micro-henrys}$$

The angle "a" is now readily calculated and from it the value of the plate blocking condenser may be determined.

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$$a = sin^{-1} \frac{707}{9{,}400} = sin^{-1}\, 0.0752 = 4.33°$$

$$I\, X_{C_3} = 9{,}400\ sin\ a = 707 \text{ volts}$$

$$I = \frac{20{,}000}{9{,}400} = 2.13 \text{ amperes}$$

$$X_{C_3} = \frac{707}{2.13} = 332 \text{ ohms}$$

$$C_3 = \frac{1}{332 \times 753{,}000} = 0.004 \text{ mfd.}$$

In order that unity power factor current may be taken by the tube, the plate choke must draw a reactive current equal and opposite to that taken thru the plate blocking condenser. This is given by:

$$I_{L_3} = I\ sin\ a = 2.13 \times 0.0752 = 0.16 \text{ ampere}$$

$$X_{L_3} = \frac{9{,}400}{0.16} = 58{,}700 \text{ ohms}$$

$$L_3 = \frac{58{,}700}{753{,}000} = 78 \text{ milli-henrys}$$

Grid excitation is supplied from the antenna circuit. When the antenna coil is on hand, it should not be a difficult matter to pick a point on it giving 2,300 volts which is the potential required, remembering that part of the voltage in this coil is induced by the primary current.

At 20 kilowatts, the antenna voltage is 30,900 volts, and the voltage induced in the antenna coil by the primary is

$$I_{L_1} X_M = 28.3 \times 101 = 2{,}860 \text{ volts}$$

These two voltages are practically in phase, so:

$$I_{L_2} X_{L_2} = 30{,}900 - 2{,}860 = 28{,}040 \text{ volts}$$

$$X_{L_2} = \frac{28{,}040}{46.5} = 603 \text{ ohms}$$

$$L_2 = \frac{603}{753{,}000} = 802 \text{ micro-henrys}$$

CHAPTER V

Primary Grid Coupling Applied to Doubly Periodic Circuits

Doubly Periodic Circuit

The possibility of double periodicity has been mentioned in

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the preceding section, altho the phenomenon has not been elaborated.

When a vacuum tube is used as a source of oscillations, it may furnish power at any of the frequencies for which the circuit to which it is attached is resonant, provided the grid and plate voltages have components in the proper phase and the losses are not too high. A coupled circuit in the general case has three resonant frequencies.

The analysis of a circuit of this type is given in Pierce, "Electric Oscillations and Electric Waves," Chapter XI, pages 156 to 159. Refering to Figure 33, the "apparent complex impedance of the primary circuit" is given by:

$$Z_1' = R_1 + \frac{M^2\omega^2}{Z_2^2} R_2 + j\left\{X_1 - \frac{M^2\omega^2}{Z_2^2} X_2\right\} \tag{1}$$

$$= R_1' + j X_1' \tag{2}$$

$$R_1' = R_1 + \frac{M^2\omega^2}{Z_2^2} R_2 \tag{3}$$

$$X_1' = X_1 - \frac{M^2\omega^2}{Z_2^2} X_2 \tag{4}$$

where R_1 and R_2 are primary and secondary resistances.

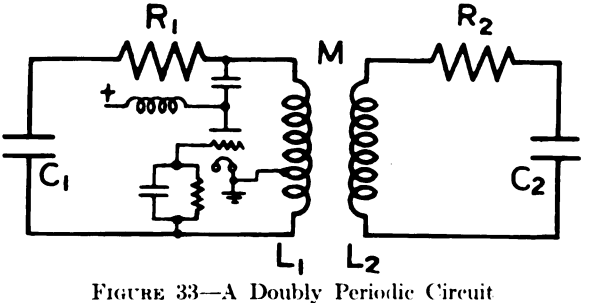

FIGURE 33—A Doubly Periodic Circuit

Z_1 and Z_2 are primary and secondary impedances consisting of inductances L_1 and L_2 and capacities C_1 and C_2.

M is the mutual inductance.

ω is angular velocity of the vectors representing the currents.

Let it be assumed that the frequencies at which the oscillator will tend to run are those for which Z_1' has no reactive component, or that:

$$X_1 - \frac{M^2\omega^2}{Z_2^2} X_2 = 0. \tag{5}$$

If it be attempted to solve this equation by substituting in

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the values for X_1, X_2, Z_2, and so on, a mass of algebraic expressions results which is practically impossible of solution and interpretation. It can, however, be solved graphically and, for the case in which the resonant points are close together, can readily be solved by tne aid of a simple approximation.

Let it be assumed that both circuits are tuned by themselves to correspond to an angular velocity (ω_o) and that the three wave lengths are expressed as variations from this of ($\Delta\omega$). Also let:

$$\left.\begin{aligned} M\omega &= M_{\omega_o} = M_o \text{ (a constant)} \\ X_1 &= 2\,L_1\,(\Delta\omega) \\ X_2 &= 2\,L_2\,(\Delta\omega) \end{aligned}\right\} \quad (6)$$

Then
$$2\,L_1\,(\Delta\omega) - \frac{M_o^2 \cdot 2\,L_2\,(\Delta\omega)}{4\,L_2^2\,(\Delta\omega)^2 + R_2^2} = 0$$

Or
$$8\,L_1\,L_2^2\,(\Delta\omega)^3 + \{2\,L_1\,R_2^2 - 2\,L_2\,M_o^2\}(\Delta\omega) = 0$$

The three roots of this equation are:

$$(\Delta\omega) = 0 \text{ and } (\Delta\omega) = \pm\frac{1}{2}\sqrt{\frac{M_o^2}{L_1\,L_2} - \frac{R_2^2}{L_2^2}} \quad (7)$$

Two of these roots may be imaginary, in which case there will be only one wave length. The necessary condition is:

$$M_o < R_2\sqrt{\frac{L_1}{L_2}} \quad (8)$$

Using the approximations outlined above, the apparent reactance and resistance of a proposed set have been calculated using:

$R_2 = 0.5$ ohms
$M_o = 1.46$ ohms
$L_1 = 0.000{,}443$ henry
$L_2 = 0.001{,}430$ henry
$R_1 = 0$
$\omega_o = 115{,}000$
Desired output 200 kilowatts.

The values obtained have been plotted in Figure 34. A_1, A_2, and A_3 are the three points on which the oscillator might run.

By having the primary tune at a slightly different frequency from the secondary, it is possible to shift the resonant points to three other values, such as B_1, B_2, and B_3.

Power Delivered at "Side" Frequencies

Let M_s be the coupling in ohms used in attempting to run on

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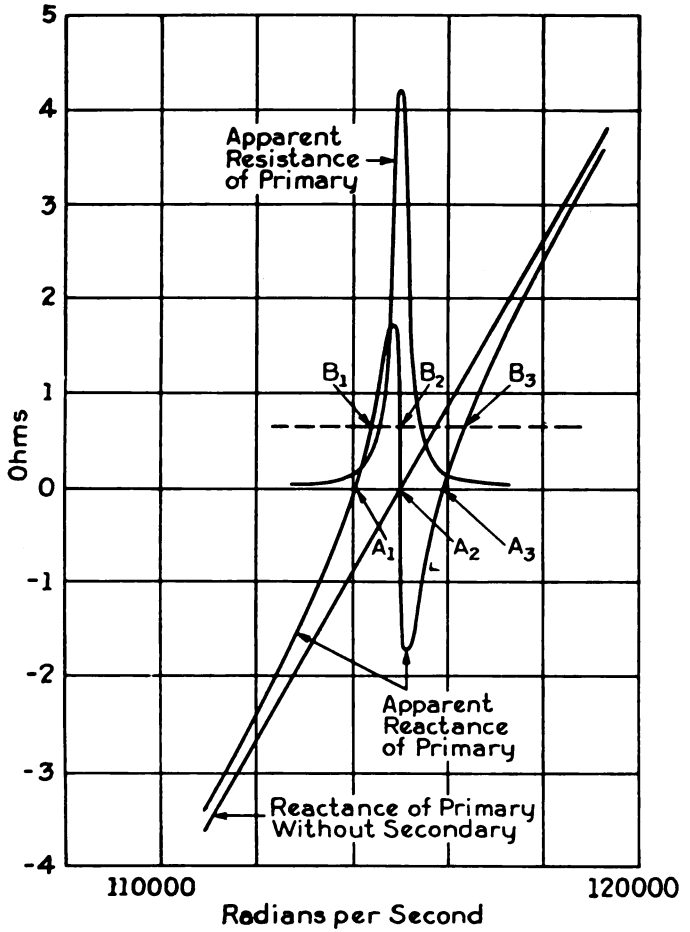

FIGURE 34—Apparent Resistance and Reactance of a Primary Circuit Coupled to a Secondary

$R_1 = 0$	$L_1 = 0.000{,}443$ henry
$R_2 = 0.5$ ohm	$L_2 = 0.001{,}430$ henry
$M_c = 1.46$ ohms	$\omega_c = 115{,}000$ radian/sec.

the "side" frequencies with the two circuits tuned alike. Then, if M_c is the coupling required to get the power across on the "center" frequency, they are connected by the equation

$$M_s^2 = \frac{4 L_2^2 (\Delta \omega)^2 + R_2^2}{R_2^2} M_c^2 \qquad (9)$$

Now the expression for the side frequencies may be written

$$(\Delta \omega)^2 = \frac{M_c^2}{4 L_1 L_2} - \frac{R_2^2}{4 L_2^2}$$

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and substitution of the value of $(\Delta\omega)^2$ as given by the latter equation into the former results in

$$M_s = \sqrt{\frac{R_2^2 (M_c^2 - 1)}{R_2^2 - \frac{L_2}{L_1}}} \tag{10}$$

Substitution of the values for the proposed set result in an imaginary value for M_s, showing that special means will be required to get the power across.

The criterion of double periodicity with its resulting limitations upon energy transfer may be more conveniently expressed than by the relation

$$M_o \leq R_2 \sqrt{\frac{L_1}{L_2}}$$

The two circuits being adjusted to the same period $X_1 = X_2 = 0$, and energy transferred from one circuit to the other will be at unity power factor. Using the equality

$$I_2 = \frac{E_m}{R_2} = \frac{I_1 M_o}{R_2} = I_1 \sqrt{\frac{L_1}{L_2}},$$

volt-amperes primary are $I_1^2 \omega L_1$. The energy component is assumed not to affect the total appreciably. Secondary volt-amperes are from the above

$$I_2^2 \omega L_2 = I_1^2 \frac{L_1}{L_2} \omega L_2 = I_1^2 \omega L_1 \tag{11}$$

That is, if the secondary volt-amperes are equal to or less than the primary, then the circuit is singly periodic. If they should be more, provided the frequency remained unchanged, the circuit is trebly periodic.

The maximum power which can be delivered to the secondary of a singly periodic coupled circuit is

$$\frac{E_m^2}{R_2} = \frac{(I_1 M_o)^2}{R_2} = \frac{I_1^2 R_2^2 \frac{L_1}{L_2}}{R_2} = I_1^2 R_2 \frac{L_1}{L_2}$$

The power consumed in the primary is $I_1^2 R_1$, therefore the efficiency of transfer is

$$\frac{I_1^2 R_2 \frac{L_1}{L^2}}{I_1^2 R_1 + I_1^2 R_2 \frac{L_1}{L_2}} = \frac{R_2 L_1}{R_1 L_2 + R_2 L_1}$$

or, rearranging,

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$$\text{Efficiency} = \frac{\frac{R_2}{L_2}}{\frac{R_2}{\omega L_2} + \frac{R_1}{\omega L_1}} \qquad (12)$$

That is, efficiency is equal to the power factor of the secondary divided by the sum of the primary and secondary power factors for the case where primary and secondary volt-amperes are equal. If the coupling is less, the efficiency of transfer will also be less.

The foregoing argument does not exclude the possibility of practical operation with a poly-periodic circuit as will be shown.

Primary Grid Coupled Circuit

It has been demonstrated that, in the case of coupled circuits one of which is driven by a thermionic valve, Figure 33, there is a critical condition determined by the relation that the volt-amperes in both circuits are equal. If there are more volt-amperes in the driving circuit, the system will always oscillate at one frequency. If there are more volt-amperes in the driven circuit, there will be two frequencies at which the system may oscillate. In the interests of efficiency and economy of apparatus, it is not desirable to circulate as many volt-amperes in the tube tank circuit as in the antenna, so that the doubly periodic circuit should be used.

If a thermionic valve be attached to the primary, oscillations will take place at frequencies, such that X_1' is zero, for the case where grid and plate voltages are displaced 180°, or nearly zero, if the 180° relation is not exact, that is:

$$X_1 = \frac{M^2\omega^2}{Z_2^2} X_2$$

as given by equation (5). This equation (5) is most easily solved graphically and, provided $M\omega > R_2\sqrt{L_1/L_2}$, may have three roots two of which represent stable operating points. Figure 35 shows the general nature of the curves of X_1 and $\frac{M^2\omega^2}{Z_2^2} X_2$. On this figure are also plotted the corresponding values of $\frac{M^2\omega^2}{Z_2^2} R_2$.

Since R_2 is constant, the variation in the apparent primary resistance due to R_2 represents a variation in secondary current The higher the apparent resistance, the higher the secondary or antenna current. X_1' is also plotted and the three frequencies at which it is zero are indicated by f_o, f_1, and f_2.

That f_o is unstable, appears from the following reasoning

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Suppose the frequency to increase a small amount from f_o; then that part of the apparent primary reactance due to the secondary becomes capacitive. This equivalent capacity in series with C_1 gives an equivalent value smaller than C_1. The circuit, therefore, has a resonant point still higher and the frequency continues to increase. On the other hand, if the frequency momentarily falls below f_o, that part of the apparent primary reactance due to the secondary circuit is inductive. This inductance added to L_1 gives a circuit resonant at a still lower frequency. The frequency, therefore, always tends to depart from f_o in the direction of the initial impulse. Corresponding reasoning will show that f_1 and f_2 are stable frequencies.

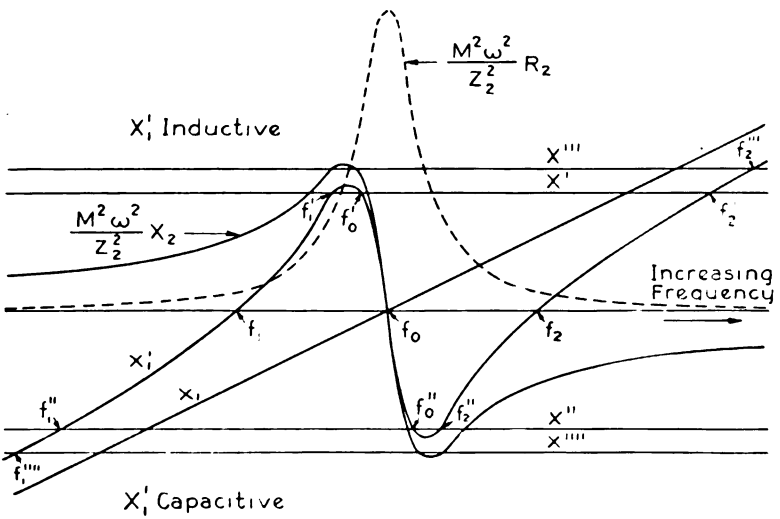

FIGURE 35 – Apparent Primary Impedance of Coupled Circuits

It follows that stable frequencies lie on both sides of the zone included between the two maxima of the apparent reactance curve. The stable points may be brought separately as close to the maxima as desired by tuning primary and secondary to different natural periods, the effect being to displace the axis and give resonant points at f_o', f_1', and f_2'. The closer the resonant point is to one of the apparent reactance maxima, the greater will be the apparent resistance, and hence secondary current, so that it is desirable to secure resonance near these points.

The frequencies corresponding to the maxima of the total apparent reactance curve are functions of coupling, while those of apparent primary reactance due to the secondary are not.

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The latter points are easily determinable and, for fairly close coupling, may be used in an approximate calculation to determine coupling.

To solve for the maxima of apparent primary reactance due to the secondary, the second term of equation (4) is amplified.

$$X_2' = \frac{M^2 \omega^2 \left(L_2 \omega - \frac{1}{C_2 \omega} \right)}{R_2^2 + \left(L_2 \omega - \frac{1}{C_2 \omega} \right)^2} \tag{13}$$

For maxima:

$$\frac{d X_2'}{d \omega} = \frac{d}{d \omega} \left[\frac{M^2 \omega^2 \left(L_2 \omega - \frac{1}{C_2 \omega} \right)}{R_2^2 + \left(L_2 \omega - \frac{1}{C_2 \omega} \right)^2} \right] = 0. \tag{14}$$

The solution of (14) is somewhat involved, but may be greatly simplified under the conditions usually encountered. With a fairly efficient circuit, the two maxima will occur near enough to f_o, so that the mutual inductance in ohms may be taken as constant. That is,

$$M \omega = M_o \tag{15}$$

For such a narrow range, the change in capacity reactance with a given change in frequency is equal to the change in inductive reactance, so that the change in inductive reactance may be substituted for the change in capacity reactance. That is,

$$L_2 \omega_o = + \frac{1}{C \omega'} - \frac{1}{C (\omega_o + \omega')} \tag{16}$$

where $\omega_o + \omega' = \omega$ so that ω_o is the departure from reference frequency. (14) may now be rewritten

$$\frac{d X_2'}{d \omega_o} = \frac{d}{d \omega_o} \left[\frac{2 M_o L_2 \omega_o}{R_2^2 + (2 L_2 \omega_o^2)} \right] = 0 \tag{17}$$

Dropping constants $2 M_o L_2$ in the numerator:

$$(R_2^2 + 4 L_2^2 \omega_0^2)^{-1} - 8 L_2^2 \omega_o^2 (R_2^2 + 4 L_2^2 \omega_o^2)^{-2} = 0 \tag{18}$$

$$R_2^2 = 4 L_2^2 \omega_o^2 \tag{19}$$

$$R_2 = 2 L_2 \omega_o \tag{20}$$

$$\omega_o = \frac{R_2}{2 L_2} \tag{21}$$

To allow a safe margin for stability, a slightly larger value of ω_o should be used, say:

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$$\omega_o = \frac{3\,R_2}{4\,L_2} \tag{22}$$

or
$$X_2 = 2\,L_2\,\omega_o = 1.5\,R_2 \tag{23}$$

Now, if we refer again to (3)

(3)
$$R_1' = R_1 + \frac{M^2\,\omega^2}{Z_2^2}\,R_2$$

R_2 is the resistance of the secondary or antenna circuit. R_1 is the resistance of the primary or tank circuit. Primary current is selected to give proper tube performance and is otherwise a minimum. Primary loss is therefore known, and

$$R_1' = \frac{\text{Primary Loss} + \text{Antenna Loss}}{(\text{Primary Current})^2} \tag{24}$$

We can thus solve directly for $M\,\omega$ and M, since ω is the required angular velocity. Knowing $M^2\omega^2$, we may solve for X_1 in (4), and all quantities are known.

Where the secondary or antenna system is multiple tuned, and the coupling is to only one of the inductances used in tuning the capacity, an exact solution is quite involved. However, under ordinary conditions, the amount of energy and wattless interchange between the circuits is small enough not to change the current distribution among the various inductances. If this condition exists, the coupling obtained above is merely multiplied by the ratio of total current to the current in that part of the circuit to which the primary is coupled.

Operation of Coupled Doubly Periodic Oscillator

Referring again to Figure 35, it is apparent that when the circuit is adjusted to give good output on one of the stable frequencies, the apparent primary resistance and hence secondary current is very low for the other. If the oscillations are started by closing the direct current supply switch, they will naturally start at the frequency presenting the minimum resistance. This is automatically the wrong frequency. Once started at the proper frequency, the oscillations are stable, unless seriously disturbed, and may be reduced in amplitude to a small value and returned without any tendency to change.

However, if there is a tendency for the frequency to change with load, because of the method of connecting the tube to the circuit, stability may be momentarily destroyed, whereupon a permanent change in frequency will occur. In any case, means must be employed to cause oscillations to start at the correct frequency.

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Suppose oscillations are being generated at frequency f_2''. the driving tube being connected to form a Hartley circuit, and suppose further that a slight decrease in frequency takes place. The apparent resistance is increased. This increase of resistance in a Hartley circuit causes the frequency to fall further so that there is an element of instability when a Hartley connection is used to drive a coupled system and the circuits are tuned separately to frequencies below the frequency of oscillation.

If, on the other hand, the circuits are tuned above the frequency of oscillation f_1' with a Hartley driver, an increase in frequency increases the apparent resistance which causes the driver to tend toward lower frequency so that the condition is inherently stable.

With a Colpitts driving circuit, conditions are exactly reversed, the stable condition being obtained with the circuits separately tuned to a frequency below that to be generated.

The reason that the Hartley and Colpitt's circuits have tendencies toward change in frequency is that when the grid excitation is, for any reason, displaced in phase, the tubes pass wattless current, so that the coupled circuits no longer operate on the zero reactive current axis. This has been explained in Chapter III.

It is apparent that, if the relative tuning of the circuits is changed to correspond to the X axis at X''', there is but one point of zero reactive energy f_2''' at which oscillations must take place. At this frequency the apparent secondary resistance is very low, hence secondary current is low. Once oscillations have started, the tuning may be changed to move the axis to X''. During this change oscillations are continuously stable and persist at f_2'' with large secondary current. This then gives one method of starting a close coupled circuit at a useful frequency. This method is not altogether desirable for signaling because, altho secondary current is controlled over a wide range with stability, the "idle" wave has a different frequency from the sending wave, which is objectionable on interference grounds.

Grid Keying

It has already been pointed out that the amplitude of oscillations may be very much reduced by weakening input without changing tuning or stability. Once started, therefore, signaling may be accomplished by varying the strength of oscillations maintaining the minimum oscillation by the main tube bank or by an auxiliary source.

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It is useful to examine some possible ways of accomplishing this result. It has been suggested that the value of grid leak resistance might be increased to reduce the amplitude of oscillations. Without entering into any extended discussion of the oscillating characteristics of a tube under these conditions it is apparent that oscillations will take place, for the commencement of oscillations takes place when there is no charge on the grid condenser and the grid resistance is, therefore, immaterial. The amplitude of oscillations will be small, because plate current is somewhat proportional to grid current, and grid current is kept small by high leak resistance. Since the oscillation amplitude is small, the grid bias must be small, as there would otherwise be no grid current to maintain the bias. An approximate determination of tube loss can be made by assuming no oscillations at all, that is the limiting case. The plate potential is then the direct potential and the grid is at ground. This condition eliminates all low impedance tubes which are destroyed quickly by full impressed plate voltage with grid at ground potential. There are probably no high voltage oscillator tubes made which can stand full plate voltage with grounded grid for any considerable time.

It should be possible to reduce oscillation amplitude by external bias. This means is subject to the objection that an external bias circuit is not self-starting and oscillations reduced to a low value might cease altogether, due to some small change in impressed voltage.

Auxiliary Oscillator Keying

One advantage of an auxiliary source of oscillations is that such a source may be used both for starting and keying, the main power bank being completely shut down when the key is up. If the auxiliary source be a vacuum tube oscillator, it must have a separate oscillating circuit of its own. This circuit is tuned to the frequency to be obtained and is coupled loosely for two reasons. First, it is necessary that the coupling be loose enough to give but one frequency possibility as driven from the auxiliary source. Secondly, when the main set is in operation, current in the auxiliary must not increase to such an extent as to do it damage. The coupling may be so adjusted that, when the main set comes into operation, it will feed back just enough energy to the auxiliary circuit to remove the load from the driving tube of that circuit. Let us examine the requirements for this condition.

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Let I_a = amplitude of current in the auxiliary circuit while used as driver, and

I_b = corresponding current in that part of the main circuit to which auxiliary is coupled.

I_a' = current amplitude in the auxiliary circuit while it is being driven by the main circuit.

I_b' = corresponding amplitude in that part of the main circuit to which the auxiliary is coupled.

Z_a = impedance of auxiliary circuit.

Z_b = impedance of main circuit in terms of that portion to which the auxiliary circuit is coupled.

Z_a', Z_b' = corresponding apparent impedances.

M_a = mutual inductance between auxiliary and main circuit.

From Pierce, page 160, equations 31 and 32, for the auxiliary driving

$$I_a = \frac{E}{Z_a'} \tag{25}$$

$$I_b = \frac{M_a \omega E}{Z_b Z_a'} \tag{26}$$

Dividing (25) by (26)

$$\frac{I_a}{I_b} = \frac{Z_b}{M_a \omega} \qquad I_a = \frac{I_b Z_b}{M_a \omega} \tag{27}$$

For main circuit driving

$$I_b' = \frac{E}{Z_b'} \tag{28}$$

$$I_a' = \frac{M_a \omega E}{Z_a Z_b'} \tag{29}$$

Dividing (28) by (29)

$$\frac{I_b'}{I_a'} = \frac{Z_a}{M_a \omega} \tag{30}$$

Since we wish $I_a = I_a'$

$$I_a = \frac{I_b' M_a \omega}{Z_a} \tag{31}$$

It is desired to have the entire circuit, as driven from the auxiliary source, oscillate at one frequency only. To meet this requirement

$$M_a \omega < R_b \sqrt{\frac{L_a}{L_b}} \tag{32}$$

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With this condition fulfilled, the oscillations may take place at the resonant frequency of both circuits so that

$$Z_a = R_a, \qquad Z_b = R_b \tag{33}$$

From (27), (31), and (33):

$$\frac{I_b R_b}{M_a \omega} = \frac{I_b' M_a \omega}{R_a} \tag{34}$$

$$M_a \omega = \sqrt{\frac{I_b R_b R_a}{I_b'}} \tag{35}$$

(35) subject to the limitation (32) gives the coupling between main and auxiliary circuits with which the main circuit current may vary from I_b to I_b' and just unload the oscillator supplying the auxiliary circuit assuming zero regulation. In practice the current would rise slightly, but not enough to damage the circuit or apparatus.

The power expended by the auxiliary oscillator will be the sum of the $I^2 R$ losses in both circuits and can be readily calculated from the relations given. It is not certain just what criteria control the minimum value of I_b. Its value must be large enough to secure quick and reliable starting of the main circuit oscillations at the proper frequency.

Use of Plate Current for Keying

For moderate power telegraph sets, say 5 kw. to 20 kw., it would be desirable to have a method of maintaining small amplitude oscillations with stability and without excessive loss. With this in mind let us examine the effect of resistance in the filament ground lead bridged by a condenser. Such a resistance will give a grid bias proportional to plate current, because the filament will be above ground by the $i\,r$ drop. Under suitable conditions this should give stability and self-starting characteristics.

To find out what the required conditions are, we shall investigate the requirements for a 20 kw. water cooled tube, type UV-207, using the characteristic given in Figure 36. With a fair degree of accuracy the plate current, for negative grid potentials, may be obtained from the formula.

$$i = 0.29 \times 10^{-3} \left(E_g + \frac{1}{\mu} E_p \right)^{3.2}$$

where 0.29×10^{-3} is a constant obtained by substitution in a number of points on the characteristics. μ is about 35. In an oscillating circuit, there are two components of both grid and plate volts, one component being a constant and the other alter-

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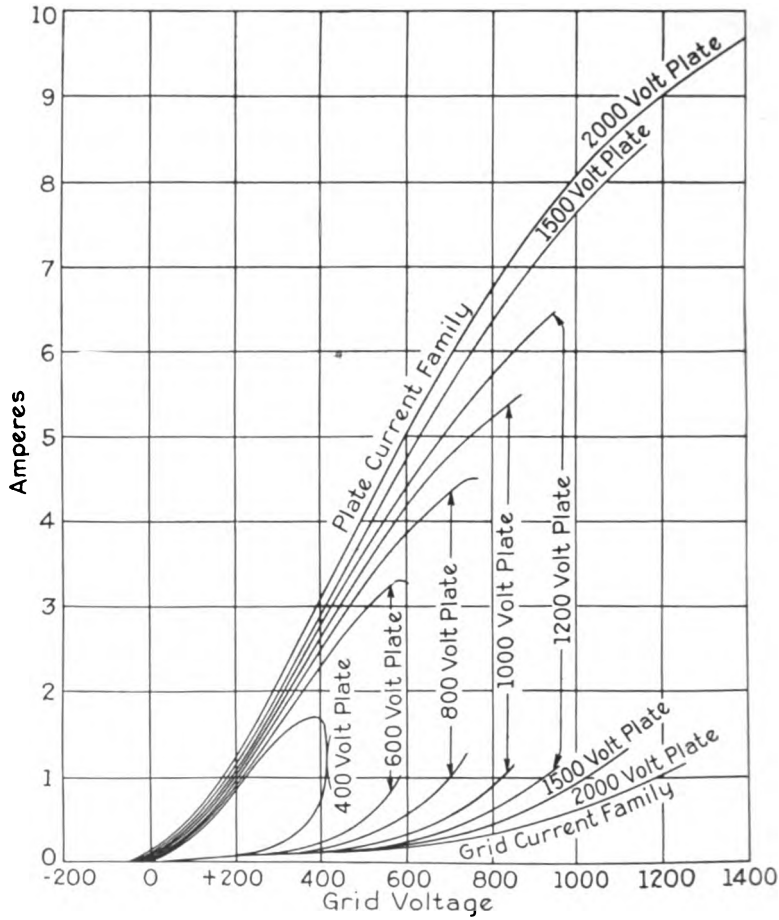

FIGURE 36—Characteristics of Water-Cooled Radiotron Number 109 at 52 Amperes Filament. Taken by Oscillograph

nating. The alternating components are proportional and are related by the circuit coupling. If ΔE_g and ΔE_p are the alternating components:

$$i + \Delta i = 0.29 \times 10^{-3} \left[E_g + \frac{1}{\mu} E_p - \Delta E_g + \frac{1}{\mu} \Delta E_p \right]^{3/2}$$

$$= 0.29 \times 10^{-3} \left[E_g + \frac{1}{\mu} E_p - \left(C - \frac{1}{\mu} \right) \Delta E_p \right]^{3/2}$$

For our purposes, C is determined by the full load adjustment and is 0.25. E_p is determined by the impressed potential and is 15,000, therefore:

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$$i + \Delta i = 0.29 \times 10^{-3} \left[E_g + \frac{15{,}000}{35} - \left(0.25 - \frac{1}{35}\right) \Delta E_p \right]^{3/2}$$

Now, $\frac{\Delta E_p}{\Delta i} = r_o$ is the equivalent resistance of the tube which is apparently negative, so that oscillations will be set up, provided $r_o < r$, the equivalent shunt resistance of the load circuit. That is, an equivalent circuit may be drawn as in Figure 37. "r" is the resistance which, if placed in multiple with resistanceless capacity C and inductance L, would give the circuit impedance. A certain circulating current in L and C sets up a potential across r and r_0. The energy absorbed by "r" is

$$W_r = \frac{E^2}{r}$$

The energy given up by r_o is

$$W_{r_o} = \frac{E^2}{r_o}$$

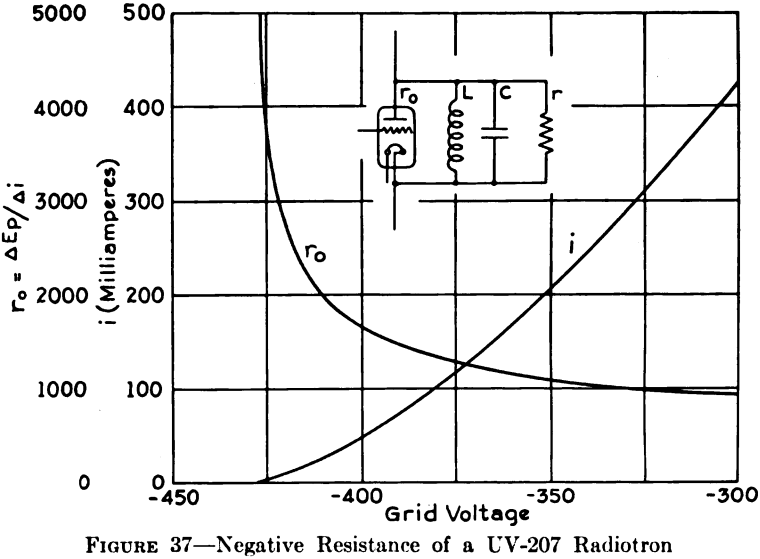

FIGURE 37—Negative Resistance of a UV-207 Radiotron

Therefore, if r_o is smaller, there is a net surplus which is stored by increased amplitude of the oscillations in L and C. By applying a series of values to E_g, the corresponding values of $\frac{\Delta E}{\Delta i}$ can be obtained and a curve plotted, giving this slope which is a measure of the negative resistance. Figure 37 shows a curve

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obtained in this way. Since the normal load corresponds to about 3,500 ohms, these figures indicate that stable low amplitude oscillations should be obtainable at a little over 0.005 amperes representing an input of 75 watts. The accuracy of the flow equation is hardly sufficient to prove that as low an amplitude as this can be maintained. However, it is apparent that low amplitude oscillations can be obtained with small loss by a bias method.

To maintain a current of 0.005 requires a grid bias of 425 volts or a resistance of 85,000 ohms in the filament ground lead.

Elimination of One Frequency by Grid Phasing

If the coupling is such as to give two oscillating frequencies, which are fairly well separated, the undesired frequency may be discriminated against by the adjustments of the circuit. One way of accomplishing this result is as follows: Referring to Figure 38: the grid circuit is inductively coupled to the primary or plate circuit and is tuned to resonate at a frequency between the operating points of the main coupled circuit. For the lower frequency, then, the grid excitation is shown in Figure 39-A, these phases being correct for oscillation. At the resonant frequency of the grid circuit, the vectors are as shown in Figure 39-B. Grid and plate voltages are in quadrature and oscillations are not maintained. At the second resonant point of the main circuit, the vectors are as shown in Figure 39-C. Here the grid excitation actually opposes any oscillations at that frequency.

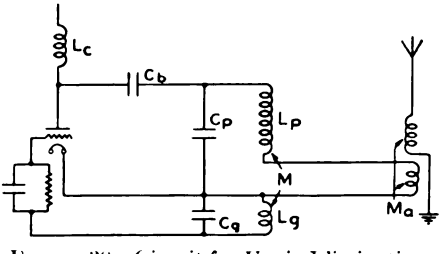

Figure 38—Circuit for Use in Eliminating Frequencies by Grid Phasing

With such an arrangement, altho the main circuit is doubly periodic, oscillations at the undesired frequency are opposed. It is necessary to have the grid coupling loose enough so as not to give rise to still further undesirable resonant points.

Simultaneous Operation at Two Frequencies

The foregoing discussion regarding change of amplitude in

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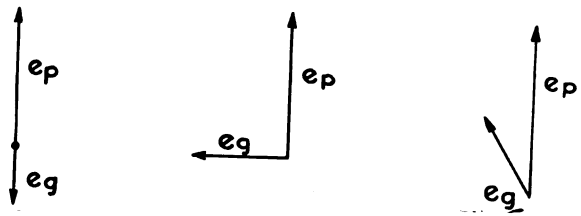

FIGURES 39-A, 39-B, 39-C. Plate and Grid Voltage Relations for Circuit Shown in Figure 38

coupled circuits is incomplete in one very important respect. A three-element vacuum tube is not limited essentially to oscillations at one frequency. On the contrary, in an unsaturated state, it can maintain simultaneously oscillations of a great many frequencies. The largest factor tending to prevent a multiplicity of frequencies is the grid bias. Since the grid is biased so that it can interrupt all currents for a considerable portion of a cycle, a predominant oscillation can maintain itself by properly synchronized pulses of current. Other frequencies in an incipient state die out during the period when no current flows and are thus unable to gain headway.

Even tho a circuit be oscillating steadily at one frequency and small amplitude, a circuit readjustment intended to increase output may render the bias momentarily insufficient to prevent the start of other oscillations. If such oscillations meet with little energy absorption they will, once started, displace the useful frequency. The likelihood of this occurrence is a time function of the change in amplitude. No quantitative derivation of this function is yet available.

APPENDIX TO CHAPTER V

CALCULATION OF A PRIMARY GRID COUPLED CIRCUIT

The circuit which is to be used is that shown in Figure 38, in which one of the resonant frequencies is discriminated against by causing the grid voltage to have the wrong phase for oscillations at the undesired frequency. It is to deliver 200 kw. at 16,400 meters, using 10 tubes operating at 15,000 volts direct current. The antenna characteristics are those given in Figure 42.

The tube characteristics as given in Figure 40 and 41 for 25 kw. output are

Tube loss = 6.6 kw. per tube.
Alternating plate volts = 9,400.
Alternating grid volts = 2,350.

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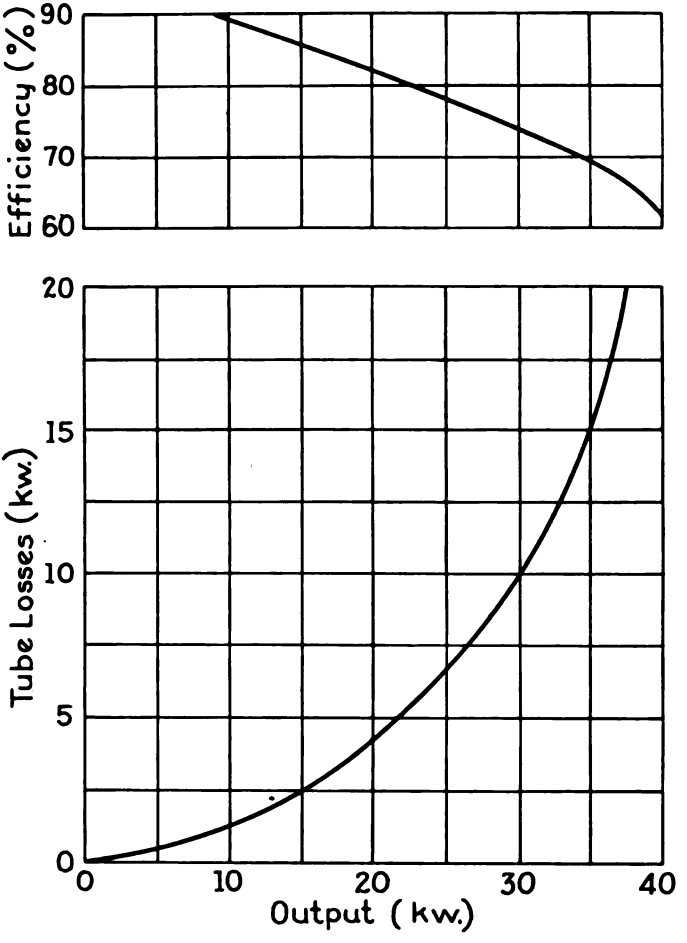

FIGURE 40—Calculated Efficiency and Losses for Best Operating Conditions of Water-Cooled Radiotron Number 109 at 15,000 volts d. c. (See Figure 36)

Estimated grid loss 8 percent of plate loss by the method of Chapter I. 25 kw. are used as a basis to allow for primary and other losses, to give a net 20 kw. per tube to the antenna.

PRIMARY CIRCUIT

Since a loose coupling to the antenna is contemplated, the volt amperes which must be stored in the primary circuit are 4π times the watts, or 2,510 kva. At 9,400 volts this represents a circulating current of 267 amperes, and the apparent resistance of this circuit, due to the secondary or antenna circuit, must be

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$\frac{200{,}000}{267^2} = 2.81$ ohms. The reactance of the condenser C_p is $\frac{9{,}400}{267} = 35.2$ ohms. The apparent reactance due to the secondary, added to the primary inductive reactance, must equal this amount.

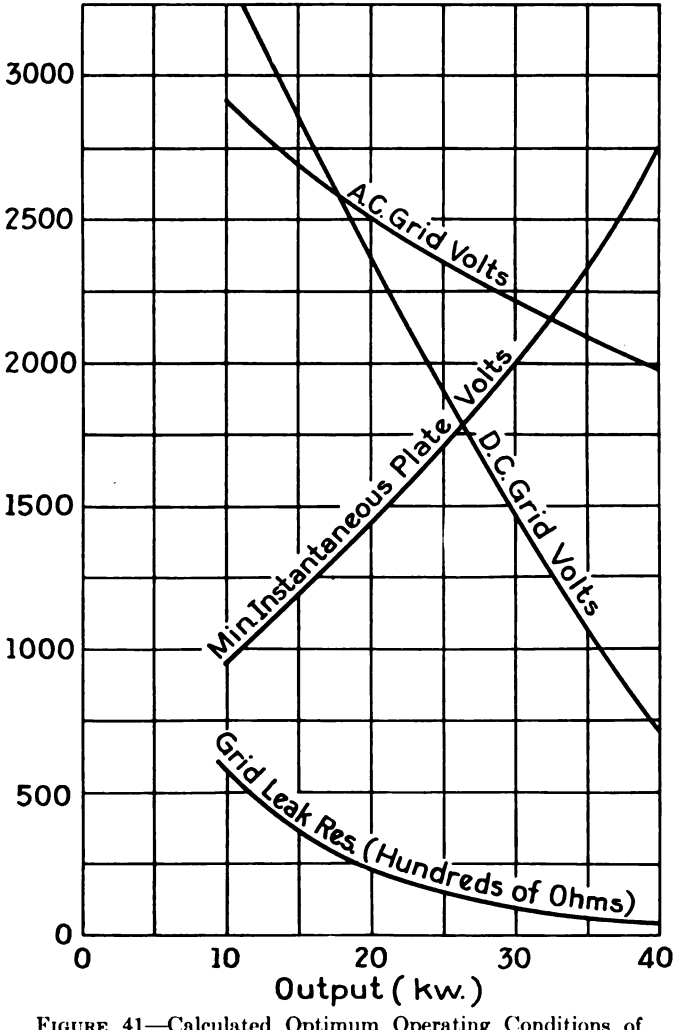

FIGURE 41—Calculated Optimum Operating Conditions of Water-Cooled Radiotron Number 109 at 15,000 volts d. c. (See Figure 36)

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Antenna Circuit

The antenna characteristics are given in Figure 42. The primary reactance for various amounts of primary mistuning is also plotted. The circuit is certainly doubly periodic, for the antenna current is $\sqrt{\frac{200{,}000}{0.5}} = 633$ amperes, so that antenna kva. are $633^2 \times 164.2 = 65{,}600$ kva., as conpared with 2,510 in the primary. The minimum coupling which would give 2.81 ohms effective resistance in the primary is seen to be between 5 and 10 ohms, but since the circuit is doubly periodic, enough additional coupling must be provided to separate the resonant points by an amount sufficient to allow the grid circuit to discriminate against one of the resultant frequencies. We will assume 20 ohms coupling. Referring to Figure 42, this gives 2.81 ohms apparent primary resistance at 99.61 percent frequency. The corresponding effective antenna reactance in the primary circuit is 7.25 ohms and the primary is mistuned 10 percent. The primary inductive reactance must be $35.2 - 7.25 = 27.95$ ohms. The second resonant frequency is found by extending the primary reactance and 20 ohm coupling curves to the right until they again cross. This occurs at slightly over 110 percent frequency. and this frequency must be discriminated against by the grid circuit. The grid circuit will be adjusted to resonate at 109 percent and will thus eliminate the 110 percent frequency point.

Grid Circuit

The vector diagram from which the grid excitation is calculated is shown in Figure 43. Starting in the primary circuit with E_{Cp} the total drop in the inductance L_p is equal to E_{Cp} and may be divided into components $I_{Lp}\ X_{Lp}$, due to the self-induction of I_{Lp} in L_p and $I_2\ X_{M_a}$ due to the mutual effect of the antenna. $I_2\ X_{M_a}$ may be further sub-divided into E_r in phase with I_{Lp} and E_x in quadrature with I_{Lp} and therefore in phase with $I_{Lp}\ X_{Lp}$. The drop in the plate blocking condenser E_{Cb} gives the plate voltage E_p, lagging behind E_{Cb}, by an angle "b."

In the grid circuit E_{Cg} must be 180° removed from E_p and $I_{Lp}\ X_M$ is 90° removed from I_{Lp}. The drop in the grid coil due to its own current is $I_{Lg}\ X_{Lg}$ and 180° removed from this is the effect of the grid circuit on the primary, an amount which is so small that it may be neglected in the calculations and which will be automatically taken care of in the final adjustments of the set.

The angle "a" is obtained from the ratio of apparent resist-

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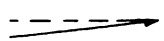

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ANTENNA CIRCUIT

The antenna char
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also plotted. The ci
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are $633^2 \times 164.2 = 65,$
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GRID CIRCUIT

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$I_{L_p} X_{L_p}$. The dro
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In the grid cir
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The angle "a"

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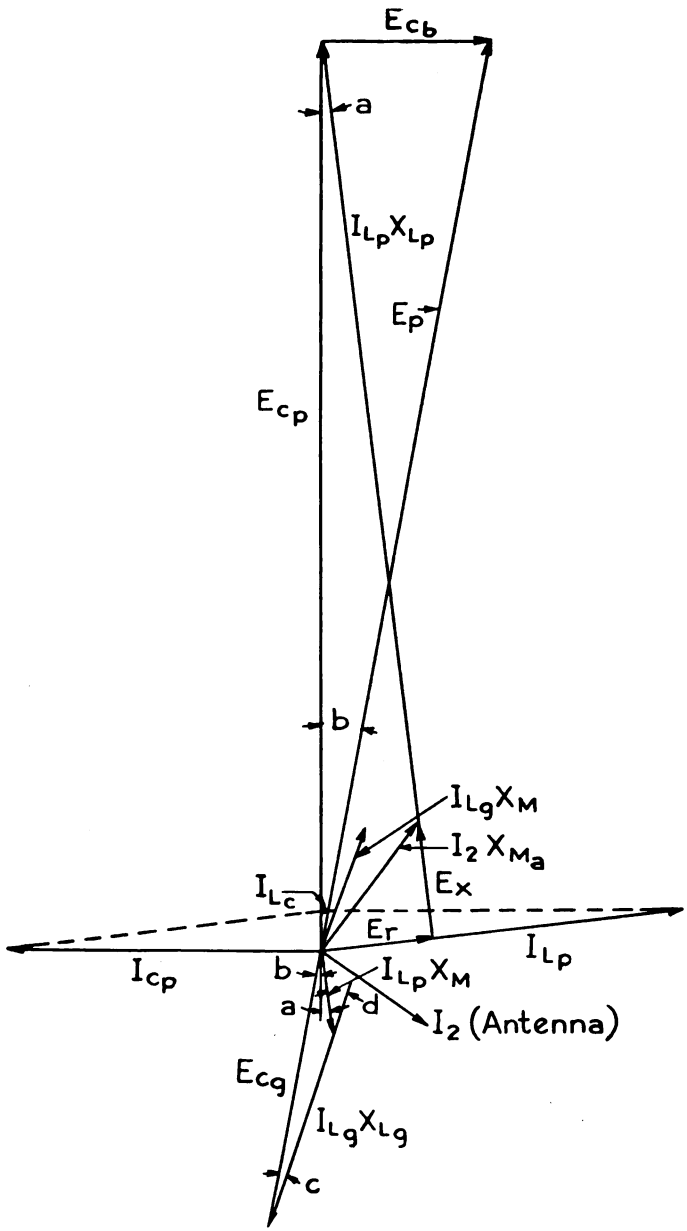

FIGURE 43—Vector Diagram of Primary Grid Coupled Circuit

ance and reactance of the primary inductance when coupled to the antenna, or

$$a = tan^{-1}\frac{2.81}{35.2} = tan^{-1}\,0.0798 = 4^\circ\ 35'$$

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The shunt resistance of the primary oscillating circuit may be calculated from the voltage and power

$$R = \frac{9{,}400^2}{200{,}000} = 442 \text{ ohms}$$

If a plate blocking condenser of 0.2 mfd. be assumed, its impedance is 43.5 ohms and

$$b = tan^{-1} \frac{43.5}{442} = tan^{-1}\, 0.0985 = 5^\circ\, 40'$$

If the grid circuit tunes at 109 percent frequency, there will be no component of grid voltage in the proper phase to produce oscillations at 110 percent and over. Assuming tuning at 109 percent frequency the grid circuit voltage diagram may be calculated by trigonometry for the value of Ec_g is known and is 2,350 volts from the second paragraph in this appendix. The angle at the origin is $a+b = 10^\circ\, 15'$ $I_{Lg} X_{Lg} = Ec_g \times \frac{1}{1.09^2} = 1{,}980$ volts.

With these two sides and angle the remaining side $I_{Lp}\, X_M$ is calculated by trigonometry to be 369 volts and the angle $c = 1^\circ\, 55'$. We thus have the voltage diagram complete, altho the currents and reactances have not yet been determined.

The source of power in this circuit is the voltage $I_{Lp} X_M$. The current is normal to $I_{Lg}\, X_{Lg}$. The power factor is

$$sin\, d = sin\, (a+b+c) = sin\, 12^\circ\, 10' = 0.211$$

The total power in the grid circuit is:
$W_g = 10 \times 6{,}600 \times 0.08 = 5{,}280$ watts. (See second paragraph of this Appendix, and hence:

$$I_{Lg} = \frac{5{,}280}{369 \times 0.211} = 67.8 \text{ amperes.}$$

This represents a circulating wattless power of 159,000 volt-amperes which is not apt to affect materially the primary where 2,510,000 volt-amperes are circulating. The length of the vector $I_{Lg}\, X_M$ is given by:

$$I_{Lg} X_M = I_{Lp} X_M \cdot \frac{I_{Lg}}{I_{Lp}}$$

$$= 369 \times \frac{67.8}{267} = 94 \text{ volts}$$

an insignificant figure as previously stated which will be corrected in tuning the primary circuit.

It will be noticed that the circulating volt-amperes in the grid circuit are much higher than are required for any energy storage effect. Two ways are available of decreasing it. First,

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$I_{L_p} X_M$ may be increased. This means that the natural frequency of the grid circuit must be further removed from its operating frequency which, in turn, requires a larger coupling between the tank and antenna circuit to insure against oscillations at the wrong frequency. Secondly, the power factor of energy transfer to the grid circuit may be increased. This requires that the angle $(a+b)$ be increased. "a" is fixed by the choice of primary kva., and the equivalent antenna resistance, but "b" may be increased by increasing the impedance of the plate blocking condenser. The first remedy is open to the objection that high power mutual inductances are difficult to build and should be kept as small as possible for this reason. Also the less the coupling the fewer the harmonics which will be transferred to the antenna. The second remedy is also far from desirable since it may lead to unexpected complications of a parasitic nature. Hence there are three factors in this circuit—grid circuit volt-amperes, coupling between primary and antenna, and phase displacement due to plate blocking condenser—which must be balanced by the judgment of the designer of the set.

Plate Circuit

The value of the plate blocking condenser has already been assumed to be 0.2 mfd. or 43.5 ohms. This results in the angle "b" being 5° 40′. Now the input current to the oscillating circuit is $\frac{200{,}000}{9{,}400} = 21.3$ amperes in phase with E_{C_p}, so that to bring the plate current into phase with E_p requires a current in L_C:

$$I_{L_C} = 21.3 \times sin\ 5°\ 40' = 2.1 \text{ amperes}$$

As the potential across it is 9,400 volts, its impedance is 4,480 ohms.

Tabulation of Constants

From the preceding calculations the values of all the capacities and inductances may be obtained and arranged in tabular form.

In giving these figures no allowance has been made for the fact that the operating frequency is 99.615 percent of the antenna frequency instead of 100 percent. This discrepancy will be taken care of when the circuit is actually adjusted. The error involved is less than the accuracy with which the various coils and condensers can be measured, and final adjustment must be made by tuning the various circuits separately with a small oscillator and wavemeter.

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Unit	Volts	Amperes	Impedance	Value
L_c	9,400	2.1 (a.c.)	4,480	39 milli-henrys
C_b			43.5	0.2 mfd.
C_p	9,400	267	35.2	0.247 mfd.
L_p		267	27.95	243 micro-henrys
M	369	267	1.38	12 micro-henrys
M_a			20	174 micro-henrys
C_g	2,350	67.8	34.7	0.251 mfd.
L_g	1,980	67.8	29.2	254 micro-henrys

RECAPITULATION OF CRITERIA

C_p has such a value that 4π times output watts will correspond to a current required to give the proper plate voltage.

M_a is assumed by inspection of Figure 42 and must be large enough to give reasonable separation of resonant points and transmit the required power.

C_b is arbitrarily assumed. The test of its choice is whether L_c is found to have a reasonable value and whether proper grid phasing can be obtained.

L_p follows from the choice of M_a.

L_c must take as many volt-amperes lagging as C_b takes leading.

The directions of grid circuit voltage vectors are fixed because E_{c_g} must be 180° from E_p and $I_{L_p} X_M$ must be 90° from I_{L_p}. If the circuit is to tune at 109 percent frequency

$$I_{L_g} X_{L_g} / E_{c_g} = \frac{1}{1.09^2}.$$

The grid requirements set the length of E_{c_g} and the circuit losses determine what the remaining constants must be.

(To be concluded)

SUMMARY: Chapter IV. The general method of designing any but the simplest of circuits is to draw a vector diagram and then calculate circuit constants that will give vectors of the proper lengths and directions. This method has been exemplified by designing a circuit in which the grid is tuned and contains the load. The plate circuit is magnetically coupled and is partially tuned to act as an harmonic by-pass. A numerical example of the method is given.

Chapter V.—The criteria for double periodicity of two coupled circuits are first developed and it is shown that for a singly periodic circuit the secondary volt-amperes cannot exceed the primary. The maximum power which can be transferred to the secondary is limited by this requirement. A greater amount of energy can be transferred by a closer coupling, which results in making the circuit doubly periodic, and tuning the circuits individually to

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other than the desired frequency. High power will then be delivered on only one of the stable frequencies. The method of designing a circuit to deliver energy under such conditions is developed. Such a circuit always tends to oscillate at the frequency giving least load. It is shown that grid keying cannot be used without other modifications of the circuit. Signaling can be carried on by changing plate voltage, by maintaining a residual oscillation from an auxiliary source, by inserting resistance in the high voltage direct current circuit between filament and ground, or by discriminating against one of the stable frequencies by grid phasing. A doubly periodic circuit may even operate at both frequencies simultaneously unless proper conditions are maintained.

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DIGESTS OF UNITED STATES PATENTS RELATING TO RADIO TELEGRAPHY AND TELEPHONY*

ISSUED APRIL 24, 1923–JUNE 19, 1923

BY

JOHN B. BRADY

(PATENT LAWYER, OURAY BUILDING, WASHINGTON, D. C.)

1,452,610—M. Klosner, filed September 2, 1920, issued April 24, 1923.

ELECTRICAL CONDENSER having a set of stationary plates and a set of adjacent turnably adjustable plates contained in an air-tight casing. A weight is connected to the adjustable plates for normally maintaining the sets of plates in non-interleaved relation. The condenser is mounted with the adjustable plates on a horizontal axis thru the center of the casing with the stationary plates supported in the upper portion of the casing.

1,452,849—H. J. Round, filed December 13, 1921, issued April 24, 1923. Assigned to Radio Corporation of America.

RADIO TRANSMITTING STATION, in which the antenna system is situated at a distance from the generator, as in the case of a multiple transmitting station employing a plurality of transmitters operating simultaneously on different wave lengths. In this invention the antenna loading inductances or a portion thereof is replaced by a trunk cable extending from the foot of the antenna to the generator or power house. This cable is shielded from the earth by a system of wires which surround the cable in the form of a cage. This cage may be electrically connected with the counterpoise.

1,452,925—W. H. Nottage and T. D. Parkin, filed December 18, 1920, issued April 24, 1923. Assigned to Radio Corporation of America.

RADIO TELEGRAPH CALLING DEVICE having a balance wheel relay at the receiver. The relay consists of a spring-controlled bal-

*Received by the Editor, July 3, 1923.

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ance wheel operated by an electromagnet the circuit of which is interrupted by the oscillations of the wheel. The relay may be unaffected by ordinary received signals, yet when a train of impulses at predetermined intervals is incident upon the receiver, the oscillations of the relay are increased by the impulses sufficiently to enable it to actuate a bell or other signal or operate in some way an electric circuit for the control of apparatus. In order to operate the control circuit the calling signals must be transmitted in impulses at regular intervals corresponding to the natural oscillation period of the balance wheel of the oscillator.

1,452,957—E. H. Colpitts, filed August 23, 1916, issued April 24, 1923. Assigned to Western Electric Company.

HIGH FREQUENCY SIGNALING circuit for two-way telephonic communication where a repeater radio station is arranged to receive signals at one frequency and re-transmit the energy at a different frequency. The arrangement of the circuits is such that useless local circulation of power at the repeater station causing "singing" is prevented.

1,452,960—W. T. Ditcham, filed December 18, 1920, issued April 24, 1923. Assigned to Radio Corporation of America.

RADIO TRANSMITTER control circuit for producing signals without interrupting the oscillation generator. A primary and a secondary circuit are employed in the transmitter and a portion of one of the windings is extended to transfer energy from the primary circuit to the secondary circuit. A key is provided for short-circuiting the extended portion of the inductance for producing the signals. The extended portion of the inductance is relatively small compared to the remaining inductance in its circuit whereby the generator will oscillate at substantially the same frequency as before, but no direct effect will be imparted to the radiating antenna system.

1,453,267—J. L. Bradford, filed November 29, 1918, issued May 1, 1923. Assigned to De Forest Radio Telephone and Telegraph Company.

ELECTRON-EMITTING CATHODE AND METHOD OF MAKING THE SAME. A filament electrode is described in this patent, which discards the idea of coatings on filaments. The new filament is formed in a homogeneous mass by mixing together a

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base material containing tungsten, an oxide and a chloride of metals of the alkali earth group, and then amalgamating the mixture into a solid bar from which the filaments may be swaged or drawn. The object of manufacturing the electron filament material is to secure a more constant and uniform electron-emitting body having greater physical strength and more stability than coated filaments now employed.

1,454,085—E. A. Sperry, filed January 27, 1917, issued May 8, 1923.

ELECTRIC INDICATOR FOR VIBRATIONS OF THE AIR which makes use of a long spindling slender gas flame which is acted upon by vibrations of air changing its characteristics. A plurality of conductors are arranged adjacent to the flame, one being nearer the base of the jet than the others and thereby unequally heated. Any change in the flame causes increase in the unequal heating and changes the conductivity of the conductors which are electrically connected to employ usefully the change in current to actuate an indicator.

1,454,307—A. L. Anderson, filed December 23, 1919, issued May 8, 1923. Assigned to Augustus Taylor.

RADIO TELEGRAPHY using the arc as a transmitter. The invention provides a uni-wave arc signaling circuit. A radiating antenna circuit and a non-radiating circuit or absorbing circuit shunted about the arc generator are provided. Two circuits containing resistance and a key are independently coupled with each of the above circuits and one closed when the other is opened for producing the signals. The closed circuit will always contain a substantial amount of resistance.

1,454,328—A. Meissner, filed September 3, 1921, issued May 8, 1923.

RECEIVING ARRANGEMENT FOR RADIO TELEGRAPHY, wherein a tube having a common filament, two grids and two plates is employed, and a circuit provided whereby the received oscillations are impressed on one of the grids and an audio frequency oscillating current impressed on the other grid. The incoming energy is rectified and amplified and enables the local alternating current source to actuate a translating device.

1,454,532—W. E. Beatty, filed August 1, 1917, issued May 8, 1923. Assigned to Western Electric Company.

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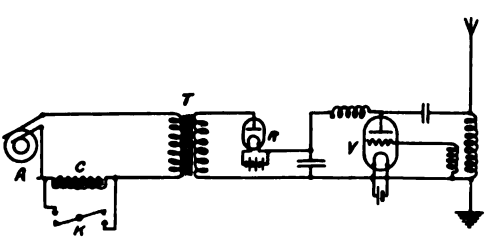
METHOD AND MEANS FOR SECRET SIGNALING for rendering radio telephonic conversation unrecognizable by the usual receiving apparatus. At the transmitter, the frequency of the carrier wave is varied gradually over a pre-determined range. At the receiver the received waves are detected by combination with a series of similar frequencies and the resultant signals combined to operate a reproducing circuit.

1,454,592—H. R. C. Van De Velde, et al, filed January 7, 1921, issued May 8, 1923. Assigned to Radio Corporation of America.

RADIO DIRECTION-FINDING MEANS FOR AND METHOD OF PILOTING AIRCRAFT, wherein the pilot of the aircraft flies the machine in a direct line to a radio beacon station located on the aerodrome which he desires to find. The direction finder includes a pair of coils disposed at right angles with each other, one being supported on a wing or plane of the aircraft and the other being supported on the fuselage of the machine. A radiogoniometer is connected with the loop circuits. The search coil of the instrument is mounted to rotate with control wires secured to the rudder bar in such manner that when the rudder is moved in a clockwise direction the search coil is rotated in a counter-clockwise direction always to maintain the circuits in proper relation for the reception of a particular transmitting station.

1,454,598—W. T. Ditcham, filed December 18, 1920, issued May 8, 1923. Assigned to Radio Corporation of America.



NUMBER 1,454,598—Radio Transmitter

RADIO TRANSMITTER having an oscillating valve circuit supplied from a source of alternating current with a rectifier interposed between the source of supply and the oscillating valve. An impedance is connected in the supply circuit with a key for short-circuiting the impedance and making telegraph signals. The impedance is of such value that, when it is not short-cir-

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cuited during space intervals between signals, the valve will continue to oscillate substantially at the same frequency as it normally oscillates during signal periods, but will generate only a small current compared to its normal working current. The purpose of the invention is to eliminate key clicks usually heard when keying the valve transmitter.

1,454,624—C. C. Chapman, filed April 27, 1920, issued May 8, 1923. Assigned to Augustus Taylor.

RADIO TELEGRAPHY SIGNALING SYSTEM employing the arc generator with a circuit arrangement for signaling by a single frequency eliminating the presence of the compensating wave. An oscillatory absorbing circuit is arranged to be connected with the arc generator with an interrupter for alternately completing the absorbing circuit or the antenna circuit at an audio frequency. The radiating signals have a group frequency within the range of audibility so that the groups may be received and detected by a receiver which would respond to radio frequency continuous waves.

1,454,629—H. F. Elliott, filed June 6, 1921, issued May 8, 1923. Assigned to Augustus Taylor.

RADIO TELEGRAPHY SIGNALING SYSTEM employing an arc generator for efficiently transmitting with a single wave. An absorbing circuit is employed connected to simulate the characteristics of the antenna circuit between signals. A plurality of "sector secondary circuits" are inductively coupled with the inductances in both the antenna circuit and the absorbing circuit. A key is placed in each of the segments in the sector circuits whereby all of the circuits may be closed or opened simultaneously to change the electrical constants of the oscillatory circuits alternately for producing the signals. A connection is taken from the central point of the sector circuits to ground for discharging the current induced in the sector circuits.

1,454,630—H. F. Elliott, filed June 6, 1921, issued May 8, 1923 Assigned to Augustus Taylor.

RADIO TELEGRAPHY signaling system employing an arc circuit for signaling with a uni-wave. An oscillatory circuit is shunted around the arc generator circuit with a transformer coupling the oscillatory circuit with the antenna circuit. A keying circuit including inductances and resistances is coupled

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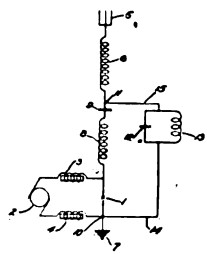
thru said inductances with the inductance in the antenna circuit and the inductance in the oscillatory circuit. The antenna and the local oscillating circuits are tuned to the same frequency, and by varying the electrical constants of one circuit or the other, the arc is caused to oscillate on one circuit to the practical neglect of the other. The residual current which usually exists in the antenna circuit is reduced by employing the coupling between the local oscillatory circuit and the antenna circuit.

1,454,652—H. Pratt, filed November 22, 1921, issued May 8, 1923. Assigned to Augustus Taylor.



NUMBER 1,454,652—
Radio Frequency
Transmission System

RADIO FREQUENCY TRANSMISSION SYSTEM utilizing an arc generator connected in an antenna circuit. An additional circuit is connected across the antenna load circuit which has a maximum impedance for the working wave, but which serves to by-pass or absorb currents of all frequencies except that required for transmission, and thereby the additional circuit tends to suppress the radiation of harmonics.

1,454,997—G. Greco, et al, filed April 18, 1922, issued May 15, 1923.

CRYSTAL DETECTOR formed within a dustproof dome-shaped casing which incloses the crystal and a contact wire which is bent over and placed in contact with a sensitive point on the crystal. The construction is intended to eliminate the necessity for constantly readjusting the setting of the detector to maintain a sensitive point.

1,455,099—W. R. G. Baker, filed January 5, 1922, issued May 15, 1923. Assigned to General Electric Company.

RADIO FREQUENCY SIGNALING SYSTEM employing a tube

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transmitter. The invention relates to a circuit arrangement for generating oscillations in the grid circuits of the tubes independently of any coupling with the plate circuits. A series condenser is connected in the grid circuit and shunted by a resistance for maintaining the average potential of the grids negative with respect to the cathodes. The tubes are supplied from alternating current and an interrupter provided which cuts off the power supply to a rectifier, periodically causing the production of oscillations in the transmitter tube circuits.

1,455,141—P. D. Lowell and Francis W. Dunmore, filed March 27, 1922, issued May 15, 1923.

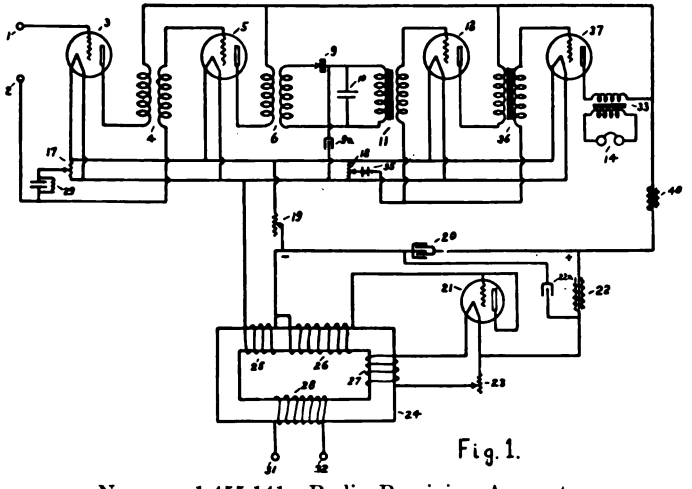

Fig. 1.

NUMBER 1,455,141—Radio Receiving Apparatus

RADIO RECEIVING APPARATUS, comprising an electron tube receiver wherein the filament and plate circuits are supplied from the house lighting circuit, dispensing with the primary and secondary batteries which have been a continuous source of inconvenience in the past. Means are provided for eliminating the alternating current hum from the receiving circuits.

1,455,458—J. S. E. Townsend, filed October 15, 1916, issued May 15, 1923.

MEANS FOR DETECTING SMALL ELECTRIC CURRENTS particularly adapted for wave meters. An evacuated bulb having its filament connected in series with a choke coil and a battery of sufficient strength to heat the filament to a temperature slightly

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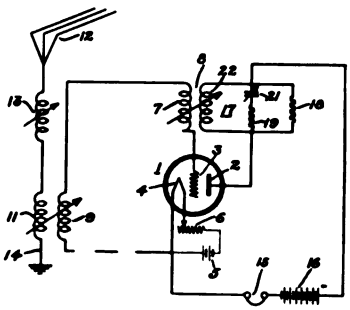
above or below the point of incandescence is employed in a series of circuit arrangements. The lamp is in a sensitive condition to show visually any small change of temperature due to the passage thru the filament of small additional current. Therefore when any radio frequency at a proper resonant period is superimposed on the circuit, the lamp becomes a quantitative indicator of relative amounts of energy picked up at different frequencies.

1,455,767—J. Slepian, filed December 31, 1921, issued May 15, 1923. Assigned to Westinghouse Electric and Manufacturing Company.



NUMBER 1,455,767—Radio Receiving System

RADIO RECEIVING SYSTEM, using a regenerative feed-back circuit adjusted to a point where an increase in the amplitude of the oscillations causes a more than proportional increase in the feed-back power, tending to maintain the oscillations continuously. The unbalanced condition of the system, which is effective following the application of the signal impulses, is made stable a pre-determined time interval thereafter by means of thermally responsive elements having a time lag in their response. The maximum amplitude attained by the oscillations at the end of said time lag is dependent upon the intensity of the impulses tending to unbalance the system. The thermally responsive elements are connected in shunt with the coupling coil in the plate circuit of the tube and have a high negative temperature coefficient and a definite time lag.

1,455,768—J. Slepian, filed January 20, 1922, issued May 15, 1923. Assigned to Westinghouse Electric and Manufacturing Company.

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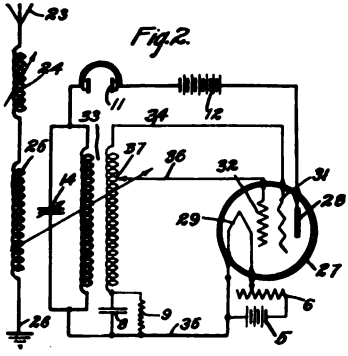

NUMBER 1,455,768—Radio Receiving System

RADIO RECEIVING SYSTEM of the regenerative feed-back type having a provision for causing the circuit to oscillate intermittently, the oscillatory current being controlled by the intensity of the received signals. A circuit for securing intermittent oscillations at the receiver by this method is shown in the accompanying cut.

1,455,781—W. Dubilier, filed December 7, 1921, issued May 22, 1923. Assigned to Dubilier Condenser and Radio Corporation.

ELECTRICAL CONDENSER in which a plurality of condenser sections are employed and connected in parallel thru a light fusable conductor so that should any of the sections become inoperative by short-circuit, they will be automatically disconnected from the circuit by destruction of the fuse elements.

1,455,795—L. Logan, filed December 20, 1920, issued May 22, 1923.

MEANS FOR CONTROLLING A PRODUCTION PROCESS utilizing radiant energy in the form of light waves. Light is directed upon a light-sensitive cell, and the amount thereof controlled by a mechanical movement which is desired to reproduce by a reverse process at a receiver. Many applications of the invention are listed in the specification such as the accurate measurement of an object, the determination of dimensions of optical glass, the control of liquid level in a tank by light reflection, and rotary shaft movements.

1,455,845—N. Lea, filed May 2, 1921, issued May 22, 1923.

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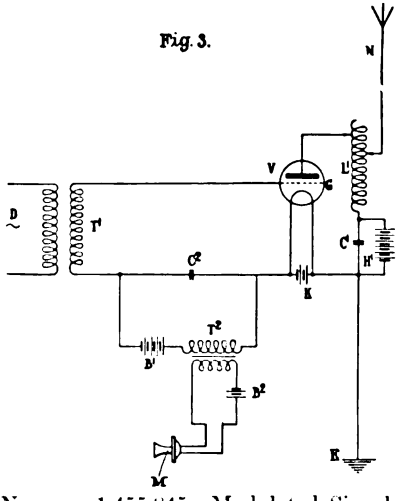
Fig. 3.



Number 1,455,845—Modulated Signaling System Particularly Applicable to Radio Signaling

Modulated Signaling System Particularly Applicable to Radio Signaling, in which an electron tube circuit is provided having a source of radio frequency oscillations connected in the grid circuit and a microphone for modulating the source also connected in the grid circuit. The grid potential is fixed at a negative value of greater magnitude than that sufficient to reduce the anode current approximately to zero.

1,455,896—L. B. Turner, filed February 9, 1921, issued May 22, 1923.

Radio Telegraph Receiver arranged for high speed signaling. The patent points out that receivers are limited in operating speed by the slowness with which oscillations die away during the space interval immediately following the signal. By this invention the receiving circuit is "curbed" by connecting a relay in a portion of the output receiver circuit which automatically increases the decrement of the oscillatory circuit when the amplitude of the received current reaches the operative value. The circuit retains the increased decrements a substantial time during the space interval following the signal.

1,456,505—W. A. Knoop, et al, filed May 12, 1919, issued May 29, 1923. Assigned to Western Electric Company.

Electric Discharge Device in which the frame for the

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electrodes of the tube is imbedded in the glass press of the tube, which frame supports the electrodes and also serves to provide electrical connections between the electrodes and the terminal points on the tube. A block of insulating material serves to support the frame wires at the upper extremity thereof.

1,456,528—H. D. Arnold, filed May 10, 1915, issued May 29, 1923. Assigned to Western Electric Company.

ELECTRIC DISCHARGE DEVICE designed so that the electrodes do not retain an amount of occluded gases to vary the vacuum in the tube during the life of the tube. The plate electrode is composed of a narrow strip of metal which is folded back and forth on itself to provide a ribbon plate electrode free from occluded gases, which might be contained in a solid plate electrode and which later manifest themselves during the operating life of the tube.

1,456,504—W. G. Houskeeper, filed April 13, 1920, issued May 29, 1923. Assigned to Western Electric Company, Incorporated.

ELECTRODE SUPPORTING DEVICE which avoids the necessity of wires being imbedded in the glass frame within the tube. The wires which support the electrodes are twisted over a glass frame and are then secured to the electrodes, avoiding the necessity for imbedding the support wires in the glass.

1,456,595—C. A. Hoxie, filed April 13, 1918, issued May 29, 1923. Assigned to General Electric Company.

RECORDING APPARATUS of the photographic type in which the incoming signals produce movement of a diafram which in turn vibrates a mirror reflecting light on a sensitive film which is developed to provide a record of the received signals.

1,456,867—F. Conrad, filed May 15, 1919, issued May 29, 1923. Assigned to Westinghouse Electric and Manufacturing Company.

APPARATUS FOR THE RECEIPT OF RADIO IMPULSES for radio control purposes. The receiving circuit is rendered highly selective by dynamically interlinking the receiving relay with the antenna thru two local circuits, one of which is tuned to resonate to the radio frequency and the other of which is tuned to resonate to the spark or group frequency of the transmitter.

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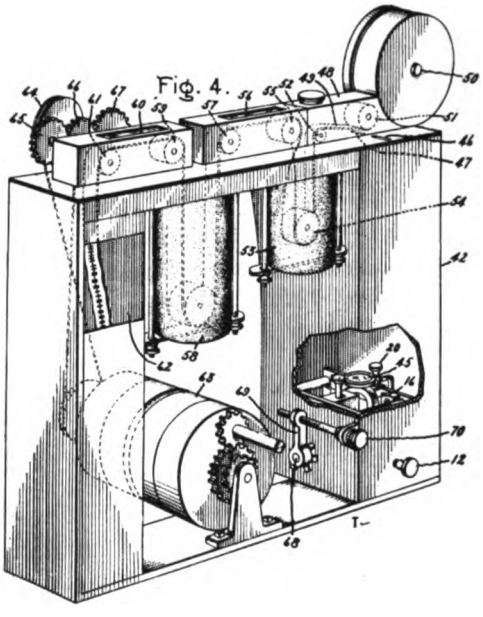

NUMBER 1,456,595—Recording Apparatus

1,457,069—L. Levy, filed September 27, 1919, issued May 29, 1923.

RECEIVING SYSTEM FOR ELECTRIC WAVES, highly selective to a particular signaling frequency and substantially unresponsive to interfering signals and atmospherics. The antenna circuit is provided with a succession of frequency-selective circuits and a selective amplifier and detector employed. A succession of acoustical frequency circuits are then provided for translating the signal into a pre-determined audible frequency.

1,457,447—J. Mills, filed December 22, 1921, issued June 5, 1923. Assigned to Western Electric Company, Incorporated.

RADIO RECEIVING CIRCUITS employing successive detection circuits and two independently rotatable directive loops connected in series and tuned to different frequencies. The circuit arrangement enables duplex operation where one loop may receive from a local transmitter with an impedance varying element operated simultaneously with the rotation of the loop and the other loop may operate on a distant station.

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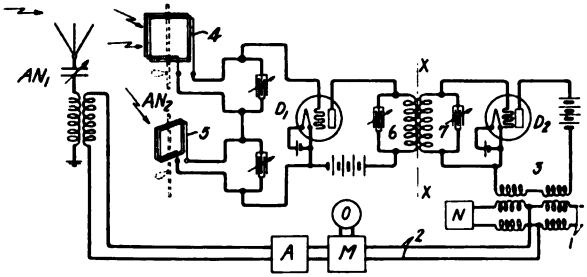

NUMBER 1,457,447—Radio Receiving Circuits

1,458,153—F. H. Shaw, filed August 20, 1919, issued June 12, 1923.

VACUUM TUBE BASE AND RECEPTACLE comprising a cylindrical shell forming the base of an electron tube inturned at one end to form a locking flange, and provided with an insulating closure molded into sealing relation with the other end of the shell. The shell is supported in the insulating material and the leads from the electrodes are carried thru the insulated material to contacts molded in the insulated closure. The tube base is supported in a socket provided with binding posts making connections with the contacts.

1,458,165—W. W. Coblentz, filed September 22, 1920, issued June 12, 1923.

SYSTEM OF ELECTRICAL CONTROL employing light rays of different coloring. A Wheatstone bridge circuit is employed at the receiver having photo-sensitive cells connected in the arms thereof with a relay circuit connected across the bridge, whereby light rays focused upon the photo-sensitive cells cause a change in the electrical conductivity of the cells, causing the relay to be operated.

1,458,466—A. Crossley, filed July 7, 1919, issued June 12, 1923.

ANTENNA SELECTOR SWITCH for combining different characteristics of antennas at a radio receiving station. The switch is illustrated in combination with four groups of ground wires extending in opposite directions. Each group of wires includes three conductors of different lengths. The ends of the conductors are connected to contact points on a switch panel. A pair of switch blades are arranged to be independently moved over the contacts to select different wires. The blades are con-

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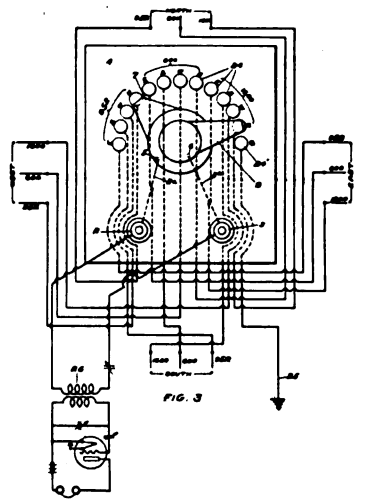
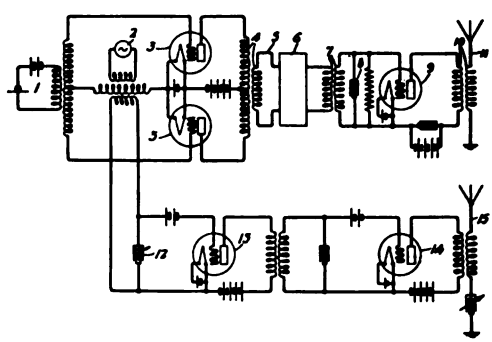
nected with the radio receiving apparatus so that different conductors may be readily chosen to secure the best radio receiving results.



NUMBER 1,458,466—Antenna Selector Switch

1,458,949—H. W. Nichols, filed January 7, 1922, issued June 19, 1923. Assigned to Western Electric Company, Incorporated.



NUMBER 1,458,949—Carrier Radio Telephone System

CARRIER RADIO TELEPHONE SYSTEM, in which one side band component of the modulated wave is radiated and the carrier wave separately radiated. At the distant receiver these frequencies are combined to translate the signal. The object of the

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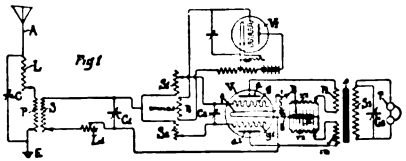
invention is to provide a system where the capacity of the amplifiers required for a given amount of useful power radiated is less than 50 percent for a given power output of that in systems transmitting the carrier and both side band components.

1,459,308—D. G. McCaa, filed April 6, 1920, issued June 19, 1923. One-third assigned to Federal Telegraph Company of San Francisco.



NUMBER 1,459,308—Signaling Apparatus

SIGNALING APPARATUS, intended for the substantial elimination of static disturbances at the receiver. The secondary circuit is divided at the receiver by means of inductances S^1 and S^2 so that received signals simultaneously operate the grids of tube or tubes V. Primary windings P^1 and P^2 are connected in the respective plate circuits and differentially act upon the translating circuit S^3. The current changes in the primaries P^1 and P^2 are therefore equal, and since these primaries oppose each other in their inductive effects upon the secondary S^3, there is no response by the telephone T on receipt of undesired signals or disturbances. In order to receive the desired signals a primary P^3 is arranged to superimpose oscillations from oscillating circuit V^1 on the receiving circuit differing in frequency a selected amount from the signal frequency to produce beats which cumulatively affect the signal translating circuit.

1,459,400—C. D. Hocker, filed November 17, 1916, issued June 19, 1923. Assigned to Western Electric Company, Incorporated.

ELECTRON-EMITTING CATHODE AND PROCESS OF MAKING THE SAME, to improve the characteristics of cathodes in the following particulars:

1. To make the thermionically active coating adhere more firmly to the electrode or filament by mechanically binding the active coating materials to the filament.

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2. To increase the electron emission at any given temperature.
3. To lengthen the life of the filament at any given temperature.

A noble metal such as gold, silver or platinum is used to bind mechanically a metal of the alkaline earth group to the filament. Barium, strontium, and calcium may be used in the coating with the substance containing a noble metal and the coatings baked on the filament.

1,459,412—A. McL. Nicolson, filed April 16, 1915, issued June 19, 1923. Assigned to Western Electric Company.

THERMIONIC TRANSLATING DEVICE having a cathode comprising an insulated tube such as quartz tube, the surface of which is coated with a thermionically active coating, with a heating element within the tube for rendering the surface thermionically active. The area of the cathode is increased and the output of the tube accordingly increased.

1,459,417—P. Schwerin, filed November 1, 1916, issued June 19, 1923. Assigned to Western Electric Company, Incorporated.

ELECTRON DISCHARGE DEVICE for operating at high power. The plate electrode of the tube is continuously cooled to prevent excessive heating due to electronic bombardment from the cathode. The plate electrode is constructed in the form of a conduit having an inlet and an outlet for the flow of cooling medium therethru. The power with this type of tube may be increased, for it is not limited by the normal melting point of the anode or that temperature at which the anode would normally throw off occluded gasses if it were not water cooled.

1,450,080—L. A. Hazeltine, filed August 7, 1919, issued May 22, 1923.

METHOD AND ELECTRIC CIRCUIT ARRANGEMENT FOR NEUTRALIZING CAPACITY COUPLING, which consists in winding an additional coil over the secondary coil of the tuning system in such position that the additional coil forms a capacity shield between the primary circuit and the secondary circuit. The auxiliary coil and the secondary coil are connected with terminals of unlike polarity together, the auxiliary coil being interposed in the electrostatic field created between the coupling coils to neutralize capacity coupling.

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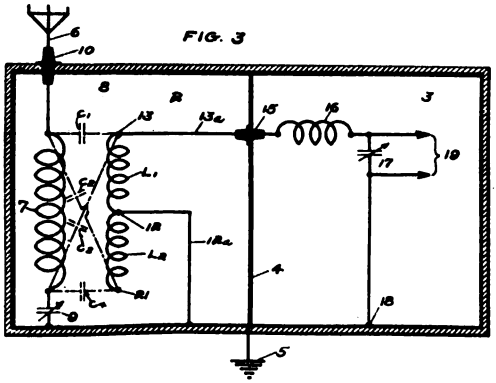

NUMBER 1,450,080—Method and Electric Circuit Arrangement for Neutralizing Capacity Coupling

LIST OF RADIO TRADE MARKS PUBLISHED BY PATENT OFFICE PRIOR TO REGISTRATION

The numbers given are serial numbers of pending applications:

153,200—"REMLER" for radio apparatus. E. T. Cunningham, San Francisco, California. Claims use since February, 1919. Published June 26, 1923.

167,229—"DE FOREST," a facsimile of Lee De Forest's signature. De Forest Radio Telephone and Telegraph Company, Jersey City, New Jersey. Claims use since 1913. Published June 26, 1923.

175,091—"LYRADION" for radio receiving apparatus. Lyradion Manufacturing Company, Mishawaka, Indiana. Claims use since about March, 1922. Published June 26, 1923.

175,472—"HIS DADDY'S CHOICE" for radio transmitting and receiving sets. De Forest Radio Telephone and Telegraph Company, Jersey City, New Jersey. Claims use since December 15, 1922. Published June 26, 1923.

177,790—"LYRADION" for combined phonographs and radio receiving apparatus. Lyradion Manufacturing Company, Mishawaka, Indiana. Claims use since in or about March, 1922. Published June 26, 1923.

178,957—"CUNNINGHAM," in facsimile of signature of Elmer T. Cunningham, for radio receiving apparatus. E. T. Cun-

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ningham, San Francisco, California. Claims use since October, 1920. Published June 26, 1923.

178,783—"TUNUP" in ornamental design for radio receiving apparatus. U. S. Tool Company, Inc., Newark, New Jersey. Claims use since January 11, 1923. Published June 26, 1923.

179,337—"ADAPTAFONE" for device for attaching telephone receiver to sound amplifier. The Teagle Company, Cleveland, Ohio. Claims use since March 23, 1922. Published June 26, 1923.

179,380—"THE RADIO CONSTRUCTOR" for radio magazine. S. Newman and Company, New York City. Claims use since December, 1922. Published June 26, 1923.

179,971—"TEMPOPHONE" for telephone instruments. S. F. Stein, Williamsport, Pennsylvania. Claims use since September 27, 1922. Published June 26, 1923.

169,727—"RADIO CORPORATION OF AMERICA, WORLD-WIDE WIRELESS" in ornamental design for radio receiving, detecting, amplifying, and transmitting apparatus, and parts thereof. Radio Corporation of America, New York City. Claims use since April 19, 1922. Published June 26, 1923.

177,552—"LISTEN-IN" for radio record books. E. Fleming and Company, Cambridge, Massachusetts. Claims use since March 8, 1923. Published May 22, 1923.

164,317—"VENUS" for radio receiving sets. Horne Manufacturing Company, Jersey City, New Jersey. Claims use since April 15, 1922. Published May 29, 1923.

171,544—"THROATYPE" for loud speaker. Master Radio Corporation, Los Angeles, California. Claims use since August 10, 1922. Published May 29, 1923.

175,437—"POSACO RADIO" in ornamental design, for radio equipment. C. D. Rotter Company, Stamford, Connecticut. Claims use since July 6, 1922. Published May 29, 1923.

175,739—"RUSONITE" for detectors. Rusonite Products Corporation, New York City. Claims use since April 1, 1922. Published May 29, 1923.

175,549—"FISCHER-RADIO" in ornamental design, for variocouplers and variometers. G. H. Fischer Company. Glen-

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dale, New York. Claims use since January 15, 1922. Published May 29, 1923.

175,865—"AMSCO PRODUCTS" in ornamental design for radio apparatus. Charles Hardy doing business as Advanced Metal Stamping Company, New York City. Claims use since April 25, 1922. Published May 29, 1923.

176,400—"SODION" for radio apparatus. The Connecticut Telephone and Electric Company, Meriden, Connecticut. Claims use since about February 14, 1923. Published May 29, 1923.

176,635—"BLUE STREAK" for telephone receivers for use with radio apparatus. Marinette Electric Corporation, Marinette, Wisconsin. Claims use since May 1, 1922. Published May 29, 1923.

176,676—"NEUTRODYNE" for radio receiving sets. Louis A. Hazeltine, Hoboken, New Jersey. Claims use since February 23, 1923. Published May 29, 1923.

178,281—"AMPLICITE" crystals for detectors. Radio Mineral Company, Newark, New Jersey. Claims use since February 15, 1923. Published May 29, 1923.

109,000—"BANNARD" for radio receiving apparatus. Triangle Electric Trading Company, New York City. Claims use since 1916. Published May 29, 1923.

164,617—"WAV-OM-ETER" for radio sets and parts thereof. Washington Radio Corporation, Washington, D. C. Claims use since May 15, 1922. Published June 5, 1923.

167,482—"MURDOCK RADIO" in ornamental design, for radio receiving apparatus. William J. Murdock Company, Chelsea, Massachusetts. Claims use since on or about July 1, 1921. Published June 5, 1923.

172,494—Crystal in ornamental design for crystal detectors. Edward Reese, doing business as Standard Crystal Company, Newark, New Jersey. Claims use since on or about April 15, 1922. Published June 5, 1923.

175,740—"S L" in ornamental design for radio apparatus and parts thereof. The Sayre-Level Radio Company, Philadelphia, Pennsylvania. Claims use since on or about June 1, 1921. Published June 5, 1923.

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177,241—"MICRO VERN" for dials for radio apparatus. Pacent Electric Company, New York City. Claims use since December 5, 1922. Published June 5, 1923.

176,021—"AMPLION" for telephone receivers. Edward Alfred Graham, doing business as Alfred Graham and Company, London, England. Claims use since September, 1920. Published June 5, 1923.

178,333—"DU-TEC" for crystal detectors. Dublier Condenser and Radio Company, New York City. Claims use since October 1, 1922. Published June 5, 1923.

169,097—"ROGERS RECEIVING RADIOMETER" for radio receiving apparatus. Bertram C. Rogers, Pittsburgh, Pennsylvania. Claims use since January 15, 1922. Published June 5, 1923.

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OBSERVATIONS ON LAFAYETTE AND NAUEN STATIONS IN WASHINGTON, MARCH 1, 1922, TO FEBRUARY 28, 1923*

By

L. W. Austin

(United States Naval Radio Research Laboratory, Washington, D.C.)

(Communication from the International Union for Scientific Radio Telegraphy)

With the completion of the February observations on Nauen and Lafayette, data covering a year have been obtained, using the telephone comparator method of measurement. The comparison of the two stations mentioned is of especial interest on account of their great difference in wave length, which permits at least a first step in the study of the relation of wave length to the reception of trans-Atlantic signals.

There are three main questions to be considered: first, the determination of the correct formula for the representation of the average conditions of transmission; second, the effect of wave length on the ratio between strength of signal and atmospheric disturbance; and third, the effect of wave length on the degree of variability of signal.

For purposes of analysis, the field intensities produced by the two stations in Washington at 10 A. M. and 3 P. M. have been averaged for each month, together with the intensities of the corresponding atmospheric disturbances. The field intensities for daylight transmission over salt water, calculated from the formula:

$$E = 120\pi \frac{I_s h}{\lambda d} \varepsilon^{-\frac{0.0015 d}{\lambda}} \qquad (1)$$

assuming 480 amperes for Lafayette and 380 amperes for Nauen, are

E (Lafayette) = 31.5 microvolts per meter

E (Nauen) = 15.3 microvolts per meter.

The average observed field intensities of the morning observations, when daylight conditions prevail over the whole trans-

*Received by the Editor, June 4, 1923.

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mission path, at all times of the year, are 72.3 microvolts per meter for Lafayette, and 30.4 for Nauen. It is seen that these values are approximately twice those calculated, but that the ratio between the observed and calculated values is approximately the same in each case, being 2.0 for Nauen and 2.3 for Lafayette. This indicates that the relation between wave length and field intensity is expressed with a good degree of approximation by the above formula, and that the difference between observed and calculated values lies elsewhere. A part of the explanation doubtless lies in the fact that Equation 1 is based on the assumption that the wave propagation takes place over an infinite plane.

TABLE 1

AVERAGE MONTHLY FIELD INTENSITY OF LAFAYETTE ($\lambda = 23{,}400$ m.) AND NAUEN ($\lambda = 12{,}500$ m.) IN MICROVOLTS PER METER

	Lafayette		Nauen	
1922	10 A.M.	3 P. M.	10 A. M.	3 P. M.
March	64.0	62.0	33.2	28.1
April	82.6	60.8	43.0	31.4
May	87.1	31.1	39.8	5.5
June	58.3	17.3	33.5	4.1
July	81.6	17.6	37.2	6.4
August	69.2	20.5	31.1	5.8
September	77.5	46.8	33.8	12.7
October	70.5	45.2	28.7	19.3
November	48.9	79.0	17.0	26.3
December	....	103.0	24.0	24.2
1923				
January	....	98.5	22.3	29.6
February	82.9	95.8	21.1	26.3
Average	72.3	56.3	30.4	18.3

For the spherical earth, the assumption is true only for moderate distances. For great distances the formula must be written:

$$E = 120\pi \frac{I_s h}{\lambda r \sin \phi} \varepsilon^{-\frac{0.0015 d}{\sqrt{\lambda}}} \qquad (2)$$

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where r is the radius of the earth and ϕ the angle between the sending and receiving stations as seen from the earth's center. For the distance from Nauen to Washington the two formulas differ by about 20 percent. It is probable also that the conditions of transmission vary somewhat from year to year, so that perhaps a closer agreement between observed and calculated values can not be expected.

For the purpose of comparing the effects of wave length on transmission, without regard to the difference in transmitting power at the two stations, the Lafayette intensities in Tables 2 and 3 have been reduced to the strength of those of Nauen by dividing the observed averages by the calculated ratio of the intensities of the two stations. In Table 2, the values of the forenoon and afternoon field intensities and of the corresponding disturbances are given, and from these are derived the variability ratios and the ratios of signal to disturbance in Table 3.

The Tables show that the forenoon signals are stronger during the spring and summer than in autumn and winter. On account of the fading, the afternoon signals are very much weaker than those of the forenoon during the late spring and summer, while in winter the afternoon signals are in general somewhat stronger than the forenoon. The afternoon atmospheric disturbances are in all months stronger than the forenoon, with the exception of April at 12,500 meters, when a powerful disturbance storm in one forenoon upset the usual ratio. The Tables indicate that while the ratio of the P. M./A. M. signals for the whole year are equal at the two wave lengths, the shorter wave fades much more in the afternoon during the strong fading season beginning earlier in the year and continuing later. It is seen that the ratio of signal to disturbance in the morning strongly favors the shorter wave, while the variability in the forenoon, that is the ratio of strongest to weakest signal in each month, is greater for the shorter wave in the ratio of 6.2 to 4. The strongest signal observed in the forenoon during the whole year for the longer wave was thirteen times as strong as the weakest, while on the shorter wave the strongest signal was twenty-four times stronger than the weakest. It has been impossible to draw definite conclusions in regard to the variability in the afternoon during the fading season as, on account of the weakness of the signals and the strength of the disturbances, both stations were below audibility a number of times. This happened much more frequently in the case of Nauen than in that of Lafayette.

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TABLE 2

	λ	A. M.		P. M.	
		Signal	Disturb-ance	Signal	Disturb-ance
1922					
March.....	23,400	31.0	94	30.0	125
	12,500	33.2	33	28.1	53
April.....	23,400	40.1	160	29.5	185
	12,500	43.0	90*	31.4	48
May.....	23,400	42.4	438	15.4	990
	12,500	39.8	109	5.5	120
June.....	23,400	28.4	202	8.4	754
	12,500	33.5	87	4.1	464
July.....	23,400	39.6	191	8.5	548
	12,500	37.2	51	6.4	368
August.....	23,400	33.6	124	10.0	519
	12,500	31.1	131	5.8	440
September...	23,400	37.7	109	22.8	256
	12,500	33.8	50	12.7	132
October.....	23,400	34.5	66	22.6	162
	12,500	28.7	28	19.3	66
November...	23,400	23.6	36	38.4	55
	12,500	17.0	17	26.3	25
December...	23,400	....	30	50.0	31
	12,500	24.0	13	24.2	16
1923					
January.....	23,400	....	19	48.1	25
	12,500	22.3	9	29.6	12
February....	23,400	40.2	12	46.4	20
	12,500	21.1	6	26.3	10
Averages	23,400	35.1	123	27.4	306
	12,500	30.2	52	18.3	146

*Disturbance; storm on morning of April 14.

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TABLE 3

	λ	Signal P. M. / A. M.	Disturbance P. M. / A. M.	A. M. Signal / Disturbance	P. M. Signal / Disturbance	A. M. Signal Maximum / Minimum
1922						
March	23,400	0.97	1.33	0.33	0.24	1.62
	12,500	0.84	1.60	1.00	0.53	8.7
April	23,400	0.74	1.15	0.25	0.16	7.5
	12,500	0.72	0.51	0.48	0.66	7.6
May	23,400	0.36	2.25	0.097	0.016	12.9
	12,500	0.13	1.1	0.37	0.046	3.04
June	23,400	0.30	3.7	0.14	0.011	5.0
	12,500	0.12	5.3	0.38	0.0089	4.6
July	23,400	0.21	2.87	0.21	0.016	2.0
	12,500	0.17	7.22	0.73	0.017	1.87
August	23,400	0.30	4.18	0.27	0.019	2.5
	12,500	0.19	3.35	0.24	0.013	2.5
September	23,400	0.61	2.34	0.35	0.089	2.2
	12,500	0.38	2.65	0.68	0.096	10.7
October	23,400	0.64	2.45	0.52	0.136	2.16
	12,500	0.67	2.36	1.03	0.292	10.8
November	23,400	1.62	1.52	0.66	0.70	2.5
	12,500	1.54	1.47	1.00	1.05	9.55
December	23,400	....	1.03	....	1.61	....
	12,500	1.0	1.23	1.85	1.51	3.54
1923						
January	23,400	....	1.31	....	1.93	....
	12,500	1.30	1.33	2.48	2.46	3.9
February	23,400	1.15	1.67	3.34	2.32	1.55
	12,500	1.15	1.67	3.52	2.63	8.0
Averages	23,400	0.69	2.15	0.62	0.61	4.0
	12,500	0.69	2.08	1.13	0.78	6.2

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The strong disturbance and fading season, May to September inclusive, is the most interesting portion of the year to the American radio engineer, since most of the difficulties of reception from Europe occur during this period. The afternoon fading is due partly to what appears to be a local atmospheric absorption which is accentuated during the late afternoon in summer by the signal weakening which follows sunset at the European transmitting stations. The averages for these months have been taken separately from Tables 2 and 3 and are shown below in Table 4.

TABLE 4

AVERAGES IN THE DISTURBANCE AND FADING SEASON

Wave Length	Signal A. M.	Disturbance A. M.	Signal P. M.	Disturbance P. M.	Signal P. M. / A. M.	Signal / Disturbance A. M.	Signal / Disturbance P. M.
23,400 m.	36.3	213	13.0	614	0.355	0.212	0.030
12,500 m.	35.1	85.6	6.9	305	0.198	0.48	0.036

From this it is seen that the shorter wave fades in the afternoon 1.79 times as much as the longer. This is nearly inversely proportional to the wave length ratio which is 1.87. It also appears that the shorter wave, considering the ratio of signal to disturbance, is 2.45 times better for reception than the longer in the morning, and that the two wave lengths are practically equal in efficiency in the afternoon. The afternoon signal averages during the fading months are somewhat uncertain, for, while Lafayette could be depended on to send the U. R. S. I. signals at three o'clock, it was never quite certain that Nauen was actually sending on the days when it was not heard. On a few days, because of the pressure of other work, observations were omitted, but the importance of recording these omissions was not at first realized. These uncertainties rendered the May afternoon record of little value and also affected the early part of the June record.

The analysis for the year is somewhat at variance with the conclusions drawn from the earlier and more limited observations,

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which indicated that the wave length of 23,400 meters was much superior to 12,500 meters for summer reception in Washington. It now appears that during the difficult times of reception, summer afternoons, the signal-disturbance ratio is nearly the same for the two wave lengths, but the greater variability of the shorter wave undoubtedly leaves the balance somewhat in favor of the longer. The greater variability of Nauen may be due partly to the greater distance the signal travels overland before reaching the ocean, that is, to a local absorption at the sending end. This is supported by the fact that Ste. Assise (14,500 m.) is considerably more constant in intensity.

The signal disturbance ratio in the afternoon during the fading season (as given in the Tables) represents conditions which would appear to make reception entirely hopeless at these times, but it must be remembered that the values given represent reception without any attempt to diminish the natural intensity of the disturbances by uni-directional reception, or by other means. It is also to be remembered in considering the variability of signal, that the afternoon fading in Washington is much greater than in some places farther north, but on the other hand, it is probable that in some tropical countries even worse conditions may be found.

SUMMARY: The results of one year's observations of the signal strength at Washington, of the Lafayette Station (23,400 m.) and the Nauen Station (12,500 m.) and of atmospheric disturbances are given in tabular form and discussed. The relative usefulness of these two wave lengths for continuous communications is analyzed.

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A METHOD OF MEASURING VERY SHORT RADIO WAVE LENGTHS AND THEIR USE IN FREQUENCY STANDARDIZATION*

By

Francis W. Dunmore, *Physicist*

and

Francis H. Engel, *Assistant Physicist*

(Bureau of Standards, Washington, D. C.)

I. Importance of Wave Frequency Standardization

The rapid increase in the number of radio transmitting stations thruout the country and the subsequent increase in the interference produced by these stations has led to the assignment of new frequencies to these stations by the Department of Commerce.[1] In this new allocation the frequencies assigned to the various transmitting stations are closer together than before. These wave frequencies, in the case of the radio broadcasting stations, are 10 kilocycles apart, and the separation is even less in other classes of service. It is obvious that the effectiveness of these frequency assignments is dependent on the accuracy with which each station is adjusted to its allotted frequency, and the care with which these frequencies are maintained.

Radio inspectors and station operators will be able to maintain the stations closely on the assigned frequencies as a result of recent work by the Bureau of Standards in improving the accuracy of its frequency standards and making these standards more generally available.[2] Several independent methods of establishing the standard of frequency were used and satisfactory agreement between them obtained. It is the purpose of this paper to describe in detail one of the methods of frequency standardization. In this method the basis of the frequency

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[1] See "Report of Second National Radio Conference" in "Radio Service Bulletin," April, 1923.

[2] A brief general description of this work may be found in an article by J. H. Dellinger which appeared in "Radio Broadcast," July, 1923, page 241.

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determination was the direct measurement of the wave lengths of very short waves.

II. Principle of Method Employed

The method was based on the direct measurement, in linear measure, of the wave length of very short standing waves on a pair of parallel wires. The waves thus used as a basis had a frequency[3] of 33,000 to 19,000 kilocycles, or wave lengths from 9 to 16 meters. The production and measurement of these waves is described in III below. Frequencies of lower values, that is, in the usual radio range, are measured in terms of these ultra-radio frequencies thru a process in which accurate frequency ratios are determined from harmonics of an electron tube generator. This process makes use of the harmonics in a low-frequency (relatively long wave) generating set, which when combined with the ultra-frequency (short wave) generating set produces a beat note in a receiving set tuned to the ultra-frequency (short wave) generating set. For example, suppose a generating set *B* (see Figure 1) to be operating at a frequency of 30,000 kilocycles (10 meters), this wave length being accurately measured and maintained by a method to be described below. Another

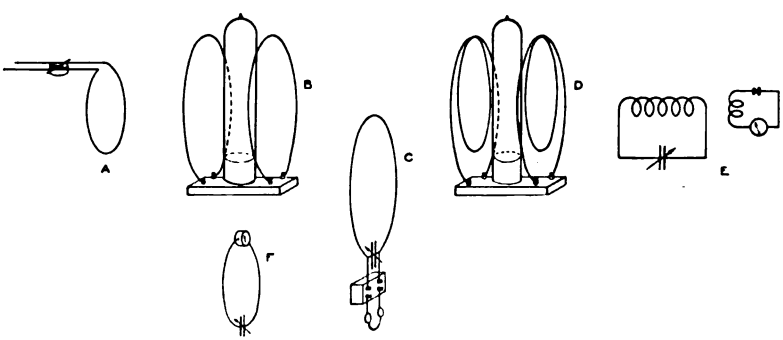

Figure 1—Arrangement of Apparatus for Wave-Frequency Standardization

generating set *D*, the frequency of which (wave length) may be varied from 30,000 to 1,000 kilocycles (10 to 300 meters) is put in operation near the first set *B*. A receiving set *C* placed near both generating sets is tuned to 30,000 kilocycles (10 meters). The wave length of *D* is adjusted until it is about equal to that of *B* by measuring it just as *B* was measured. When it is so

[3] Wave length in meters is converted to frequency in kilocycles by dividing 299,820 by the wave length. For most purposes the approximate ratio, 300,000, is sufficiently accurate.

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adjusted the difference in frequency between D and B produces a beat note which is heard in the receiving set C. This note disappears when the exact adjustment is obtained, that is, when the two frequencies are indentical. This process is known as the zero beat note method. The frequency of D is then gradually decreased until a second beat note is heard in C, and this is likewise made to disappear by exact adjustment. This beat note indicates that D has been adjusted to 15,000 kilocycles (20 meters), and that its second harmonic 30,000 kilocycles (10 meters), is producing a beat note with B which is heard at C. The wavemeter E is then adjusted to resonance with D, thus establishing the 15,000 kilocycle (20 meter) point on it. The frequency of D is further decreased until another beat note is heard in C. This means that D has been decreased to 10,000 kilocycles (30 meters), its third harmonic which is 30,000 kilocycles (10 meters) combining with B giving the beat note heard in C. The wavemeter E is then adjusted to resonance with D and establishes the 10,000-kilocycle (30 meter) point on the wavemeter. Thus by continually decreasing the frequency of D, the 4th, 5th, 6th, etc., up to the 30th harmonic may easily be utilized and the wavemeter E calibrated down to 1,000 kilocycles (300 meters). By changing the frequency of generating set B to 20,000 kilocycles (15 meters), the wavemeter E may be calibrated by a similar process down to a frequency of 300 kilocycles (1,000 meters), and so on. The method outlined above requires the following:

A. The development of apparatus for the generation of very high frequencies or short waves.

B. An accurate means for measuring waves of this order of length.

C. Means for utilizing the short-wave generating set thus standardized for determining the frequency of the low-frequency generating set which in turn is used for the calibration of the standard wavemeter.

III. Apparatus Used

A. Ultra Radio-frequency Generating Set

For the purpose of making these measurements an ultra radio-frequency generating set was necessary.[4] The one as constructed is shown in Figure 2. Figure 3 gives the circuit diagram. Coil C

[4] See "Directive Radio Transmission on a Wave Length of 10 Meters," by F. W. Dunmore and F. H. Engel. "Bureau of Standards Scientific Paper," number 469.

*Diameter of number 12 Brown and Sharpe gauge wire = 0.0808 inch = 0.0317 cm.

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consists of a single turn 18.5 cm (7.3 in.) in diameter of number 12 Brown and Sharpe gauge copper wire* for plate coupling and a similar turn *D* for grid coupling. The coils *C* and *D* were spaced about 3 cm. (1.18 in.) apart. *J* is a radio-frequency by-pass condenser and may also be used to vary the wave length slightly. The three-electrode tube used was rated at 50 watts. It was a coated filament type. The capacity between the elements of the tube together with the coils *C* and *D* form the oscillatory

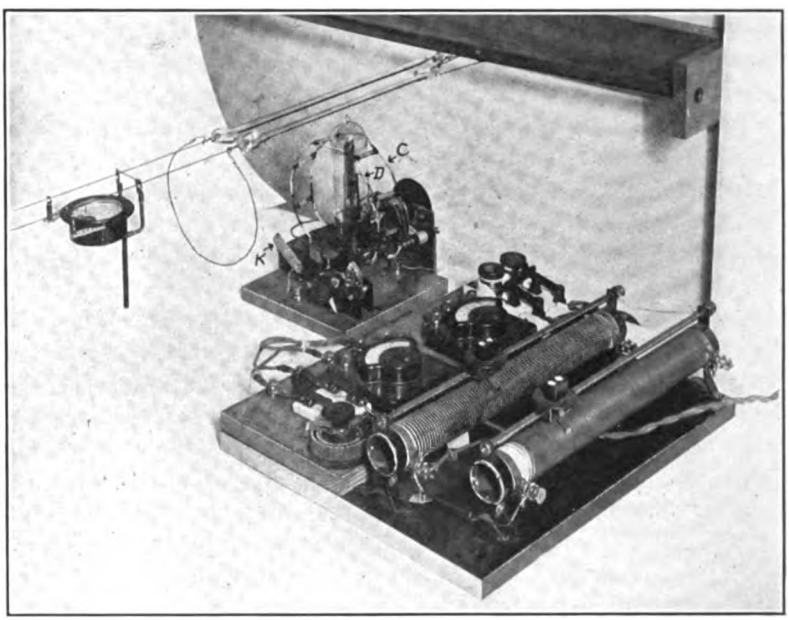

FIGURE 2—Ultra Radio-Frequency Generating Set Shown Coupled to Parallel Wire System

circuit. It is this internal capacity which determines the upper limit of the frequencies obtainable with a given tube. To keep the radio-frequency currents out of the battery circuits, three choke coils were used as shown at *K*. These consisted of thirteen turns of number 20 copper wire* wound ¼ inch (0.64 cm.) apart on a wooden core ½ inch (1.27 cm.) in diameter. These chokes were found necessary to maintain stable operation of the generating set. This generating set produced a frequency of 33,000 kilocycles (wave length of 9 meters). By connecting a variable air condenser across the grid and plate, the frequency could be decreased to 17,640 kilocycles (17 meters).

*Diameter of number 20 wire = 0.032 inch = 0.081 cm.

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B. Apparatus for Measuring Short Wave Lengths

The apparatus used for measuring[5] these ultra frequencies is shown in Figure 2.

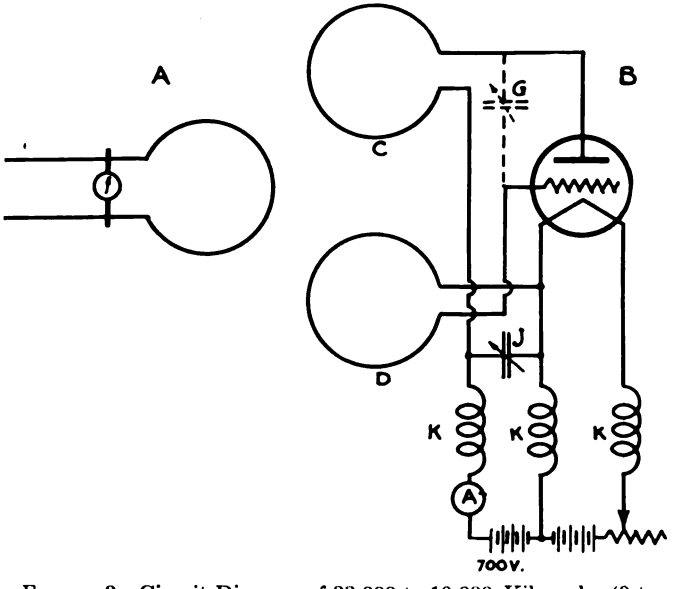

Figure 3—Circuit Diagram of 33,000 to 19,000 Kilocycles (9 to 16 meters) Generating Set

The parallel wire system used is shown terminating in a wire loop. The system consisted of two parallel number 14 bare copper wires† about 45 feet (13.7 m.) long strung between glass insulators as shown. The wires were separated about 4 cm. (1.58 in.) and were held under tension by means of two heavy springs (not shown). The ultra radio-frequency generating set was coupled to the looped end as shown. The apparatus to the right is the control panel, by means of which the output of the generating set is held constant. The wave length is measured by moving the thermo-galvanometer, to be seen suspended from the wires, along the wires until it shows a maximum indication of current. This point is marked on the wires and the galvanometer moved still further along the wires until a second current maximum is indicated. The distance between these two points of current maxima is one-half a wave length. If the parallel wires are sufficiently long, a number of such points may

[5] See "Electric Oscillations in Straight Wires and Solenoids," by J. S. Townsend and J. H. Morrell, "Philosophical Magazine," August, 1921.

†Diameter of number 14 wire = 0.064 inch = 0.0163 cm.

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be found. Considerable work was done in order to find the best method of indicating the resonance point. The one finally adopted was the sliding thermo-galvanometer as shown suspended from the wires in Figure 2. It consists of a sensitive thermo-galvanometer (full scale deflection = 115 milliamperes), the terminals of which are connected to the two wires thru sliding contacts shown at the right. The two supports at the left are insulated from the instrument. An interesting point in connection with the use of this instrument at frequencies of 30,000 kc. (10 meters) was that a low resistance shunt across the terminals of the instrument greatly improved the accuracy with which this instrument could be set on the current maxima. The shunt consisted of a piece of number 14 copper wire soldered across the instrument terminals at the sliding contact. This shunt is clearly shown in Figure 2. By the use of this shunt the resistance of the circuit was materially decreased so that the sharpness of resonance was greatly improved. In fact, the point of maximum current was so critical that a movement of the galvanometer 1 millimeter (0.04 inch) either way along the wire at the point of maximum current indication gave a very noticeable decrease in deflection. With such a sensitive indicator it is apparent that the locations of the current maximum may be accurately obtained and the distance between them determined with great precision. A calibrated steel tape was used for measuring distances on the parallel wires. Several measurements of wave lengths of the order of 9 meters have shown variations of only 1 millimeter in 4.5 meters. Thus the indicating instrument may be set on the current maximum to within an accuracy of 1 part in 4,500. Much experimental work was done on the parallel wire method of wave length measurement in order to determine any possible sources of error. Measurements were made under various conditions such as different lengths of wires, different spacing between wires, different size wire, and different methods of indicating current maximum, but none of these changes influenced the accuracy of the measurements. Measurements were also made on an entirely different parallel wire system located on the roof of the radio laboratory. As a check on the method, the results of these measurements were compared with those obtained indoors on much shorter wires, by means of ultra radio-frequency wavemeter shown in Figure 4. This instrument had a range of approximately 35,000 kc. to 32,000 kc. (8.5 to 9.5 meters) and was calibrated by means of the parallel wire system located on the roof and by two different methods of indi-

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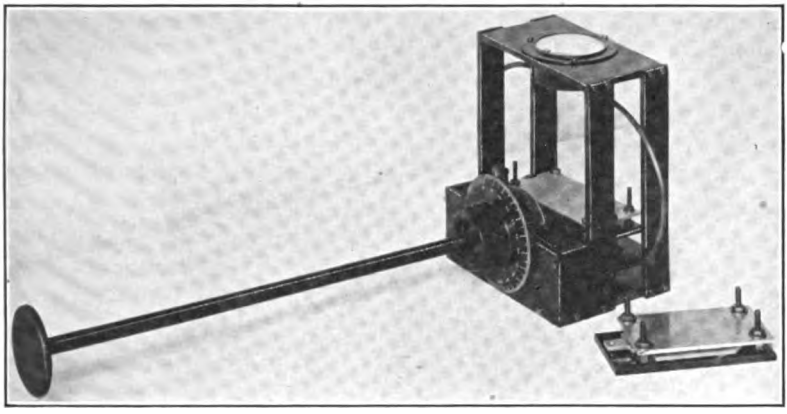

FIGURE 4—Ultra Radio-Frequency Wavemeter

cating the resonance points on the shorter parallel wire system indoors. The results of this calibration are shown in curve form in Figure 5. It will be seen from these three curves, which are practically coincident, that the parallel wire method of wave length measurement as used is reliable. This method of checking the parallel wire measurements of wave length would undoubtedly have revealed any inherent error.

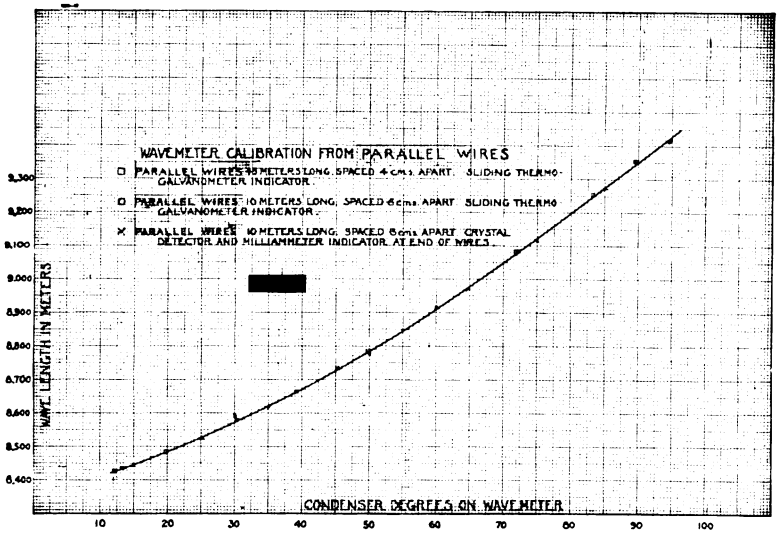

FIGURE 5

C. Ultra Radio-Frequency Wavemeter

For the purpose of investigating the accuracy of the method

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of wave length measurements on parallel wires and in order to keep a check on the steadiness of the frequency of the ultra radio-frequency generating set when using it to establish wave length standards, an ultra radio-frequency wavemeter as mentioned above was constructed. It is shown in Figure 4. This instrument consisted of a single turn of number 5 Brown and Sharpe gauge copper wire,* the terminals of which were connected to a 50 micromicrofarad 2-plate variable air condenser. A fixed air condenser was connected in parallel with the variable air condenser. It consisted of two fixed plates spaced approximately 3/64 inch (0.12 cm.) apart. The upper plate was 2⅛ inches (5.4 cm.) by 4⅝ (11.7 cm.) inches. The lower plate was 1¾ inches (4.43 cm.) by 4 inches (10.2 cm.). This air condenser was removable so that one of different capacity could be inserted, thereby increasing the range of the wavemeter. Such a 2-plate air condenser is shown in Figure 4 beside the wavemeter. A thermo-galvanometer is inserted in series with the single turn. It is shunted with a piece of number 14 Brown and Sharpe gauge copper wire 1¼ inches (3.16 cm.) long. The wavemeter condenser was provided with a long handle so that the capacity effects of the operator's body were avoided when adjustments were being made.

D. Low Radio-Frequency Generating Set

In stepping up from the wave lengths measured on the parallel wires to the longer wave lengths, ordinarily used for radio communication, a generating set rich in harmonics and variable in frequency from 300 to 16,600 kc. (18 to 1,000 meters) was employed. This is shown in Figure 6. By means of a set of interchangeable coils, the frequency may be varied over the range from 300 to 16,600 kc. (18 to 1,000 meters). A set of single-turn, two-turn, and six-turn coils are shown in the photograph. These may be easily substituted in the plate and grid circuit of the tube. The frequency may also be varied by means of three variable air condensers connected in parallel across the grid and plate of the electron tube generating set. The larger of these condensers has a capacity of 0.001 microfarad, the next 0.0001, and the smallest about 0.00005 microfarad. This latter condenser is provided with a long insulated handle so that the final adjustment for zero beat note may be more easily obtained.

*Diameter of number 5 wire = 0.182 inch = 0.461 cm.

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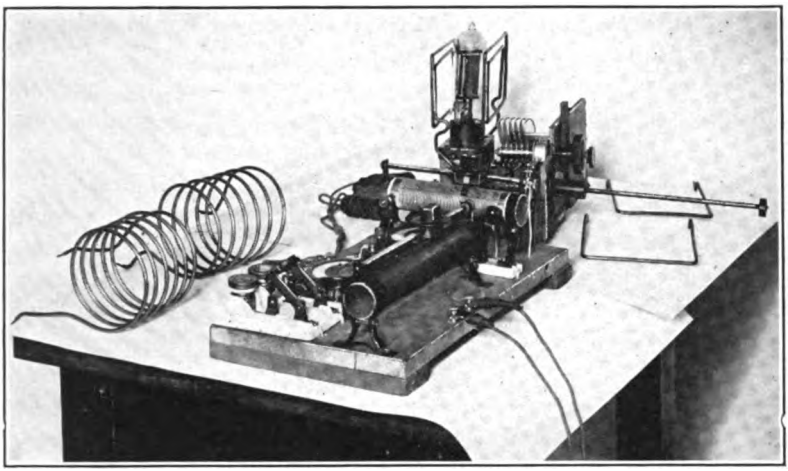

FIGURE 6—Low Radio-Frequency Generating Set

E. Ultra Radio-Frequency Beat-Note Receiving Set

An ultra radio-frequency receiving set was used for the purpose of determining when the low-frequency generating set was tuned so that one of its harmonics was equal to the frequency of the ultra radio-frequency generating set. This is shown in Figure 7. It was designed to cover a frequency range of approximately 15,000 to 37,000 kc. (8 to 18 meters). The tuning element consists of a single turn of number 12 Brown and Sharpe gauge copper wire* connected to a 0.00025 microfarad variable air condenser, the terminals of which were connected to the input of an electron tube detector with two stages of audio-frequency amplification. This receiving set was located about five feet (1.53 m.) from the two generating sets. By tuning it to the frequency of the ultra radio-frequency generating set, confusion caused by the presence of beat notes from harmonics in the ultra radio frequency generating set, was eliminated.

IV. Standard Wavemeter Calibration

The wavemeter standardized in the course of these measurements was the standard wavemeter of the Bureau of Standards.[6] The following is a detailed description of the procedure employed when calibrating the standard wavemeter using the method and apparatus described above. A comparison of this calibration

*Diameter of number 12 wire = 0.0808 inch = 0.0317 cm

[6] See "Standard Radio Wavemeter, Bureau of Standards Type R70-B," by R. T. Cox, "Journal of the Optical Society of America," volume 6, number 2, page 162.

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with two other calibrations obtained by entirely different methods agreed within 0.2 per cent.

The ultra radio-frequency (short-wave) generating set was put into operation and its wave length accurately determined by means of the parallel wire measurements. It was found to be 9.005 meters, which is equivalent to 33,290 kc. During the course of the calibration these parallel wire measurements were repeated from time to time to insure the constancy of the frequency of the generating set *B*. The wavemeter *F* was used as a constant check on the frequency of the generating set *B*, and thus reduced the number of parallel wire measurements considerably.

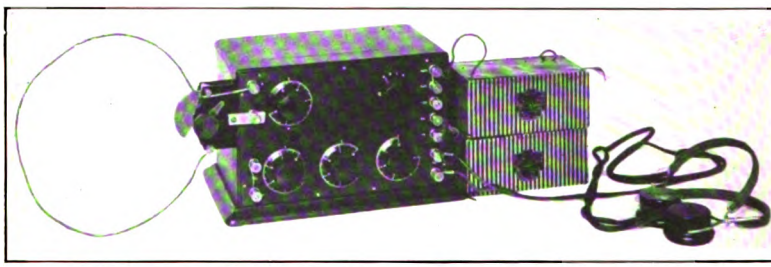

FIGURE 7—Ultra Radio-Frequency Beat-Note Receiving Set

The generating set *D*, Figure 1, was next started and its frequency adjusted to be approximately 16,645 kc. (18.010 meters) by using the parallel system. The operator using the receiving set *C* adjusted the frequency of generating set *D* until a beat note was heard. This beat note is equal to the difference in frequency between the second harmonic of generating set *D* and the fundamental of generating set *B*. Using the vernier condenser on generating set *D*, its frequency may be adjusted until the beat note becomes inaudible, thus indicating that the frequency of the first harmonic of generating set *D* is exactly equal to the fundamental of generating set *B*. From this it follows that the fundamental frequency of the generating set *D* is one-half that of the fundamental of generating set *B*, or $= \frac{33,290}{2}$ kc. $= 16,645$ kc. (18.010 meters).

The wavemeter *F* which was to be calibrated was next tuned to resonance with the fundamental of generating set *D*, the beat note being held at zero. This fixed the 16,645 kc. (18.010 meter) point on the wavemeter.

To obtain the next point on the wavemeter, the frequency of

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the generating set D was slowly decreased until a second beat note was heard at the receiving set C. This beat note indicated the presence of the third harmonic of the generating set D. No intermediate beat notes were heard because the receiving set was tuned to 33,290 kc. (9.005 meters). By careful adjustment of the generating set D, the zero beat note was obtained as before.

After this adjustment had been made, the fundamental frequency of the generating set D is one-third that of the fundamental of generating set B or $\frac{33,290}{3}$ kc. = 11,096 kc. (27.015 meters). The wavemeter E is again tuned to resonance with the fundamental of the generating set D, thus establishing the 11,096-kc. (27.015-meter) point on the wavemeter.

This process was repeated until the 34th harmonic of generating set D was reached, giving a calibration of wavemeter E up to 979.2 kc. (306.17 meters). By changing the fundamental of generating set B to 18,367 kc. (16.324 meters) the wavemeter E was calibrated by the same process to a frequency of about 352.7 kc. (850 meters).

This process can be extended to calibrate a wavemeter of much greater range by decreasing the frequency of generating set B.

Conclusion

The direct measurement of very short wave lengths by means of standing waves on parallel wires was found to be convenient, practical and accurate. The method of setting a radio-frequency generating set on a given frequency by means of the zero beat method was found to be an extremely simple and reliable one.

This in combination with the parallel wire method of precision wave length measurement gives a combination with which wave frequency standards may be accurately determined.

Radio Laboratory,
Bureau of Standards,
Department of Commerce,
Washington, D. C.
June 27, 1923.

SUMMARY: The paper describes one method of establishing frequency standards employed by the Bureau of Standards which is based on the direct measurement, in linear measure, of the wave length of very short standing waves on a pair of parallel wires. The wave lengths measured were from 9 to 16 meters, the currents having frequencies from 33,000 to 19,000 kilocycles per second. The apparatus for generating these ultra radio-frequency cur-

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rents is described, as well as the details of the method used in measuring the wave length of the waves which they produce on the parallel wires.

A method is described for calibrating a wavemeter at frequencies from 30,000 kilocycles to 352 kilocycles (10 to 850 meters). This method makes use of the harmonics in a second radio-frequency generating set, one of which, when combined with the output from the ultra radio-frequency generating set, produces a beat note in a receiving set tuned to the ultra radio-frequency. The zero beat note method is used to obtain an exact setting. Knowing the frequency of the ultra radio-frequency generating set by direct measurement on the parallel wires, and the order of the different harmonics being used in the second radio-frequency generating set, the frequency of the latter may be determined over the range from 30,000 kilocycles to 352 kilocycles (10 to 850 meters).

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AN IMPROVED SYSTEM OF MODULATION IN RADIO TELEPHONY*

By

Charles A. Culver

(Canadian Radio Corporation, Limited, Toronto, Canada)

The ideal system for effecting voice modulation of the output of a radio frequency oscillation generator has not yet been devised. An approach to such an arrangement or means would be the introduction of some agency or device whereby one might vary, by means of the voice, the normal ohmic component of the resistance of an antenna system between rather wide limits, one limit being a value greater than the normal value, and the other limit being less than the normal value. Such a device should act on the *resistance* of the radiating system alone, and only affect the primary or radio frequency power circuit as a result of changing the load in the antenna. Such a modulating device should be able to produce a radical increase and decrease in the resistance of the antenna, without a great change taking place in its own constants. While there have been developed devices which will *increase* the resistance of an antenna, there has yet to be produced the device which will *decrease* the resistance of a transmitting antenna, particularly when an appreciable amount of power is involved. We must, therefore, await with interest the development of some such device or electrical organization.

Limitations of Former Systems

Turning to existing systems, we find the two modulating schemes which are the most widely used to be the "*drainage*" *or* "*absorption*" method and the Heising or "*constant current*" method.

The drainage or absorption method may be effected either by means of the so-called magnetic modulator, or by means of tubes alone. By either scheme a part of the radio frequency energy delivered by the oscillating power circuit is diverted by or absorbed in the device and hence less radiation results. A

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number of the larger English radiophone sets utilize the drainage system, the control being effected by means of a pyramidal bank of large tubes, which in turn are controlled by the voice. The quality of the resulting speech is excellent, but the system has the obvious disadvantage that practically as many tubes are required for modulation as are required to serve as high frequency generators.

The so-called "constant current" or Heising system, as is well known, also requires the use of as much or more tube capacity for modulation as for power. This system also gives excellent quality and deep modulation. It, however, possesses a marked disadvantage other than that due to the number of tubes required. Let us examine this particular limitation.

If it be assumed that the carrier wave is represented by the relation $i = A \sin \omega t (1 + K \sin \overline{\theta}\, t)$, Heising[1] has pointed out that if K be unity, that is, if complete or 100 percent modulation obtained, "The effective radio frequency power rises to a peak value of four times the non-signaling value, and has an average value of 3/2 the non-signaling value." By the integrating the complete expression for the power thruout a complete frequency cycle there results:

$$P = \frac{3}{2}\left(\frac{A^2 R}{2}\right)$$

which leads Mr. Heising to the conclusion that "The power content of the completely modulated wave is 3/2 the power content of an unmodulated wave of the same average current."

If then in operating a radiophone transmitting set we adjust our oscillating tubes to give their maximum non-signaling output, the peak load on the tubes when complete modulation obtains, will be four-fold the quiescent load, and the tubes will be subjected to an average load the magnitude of which is 50 percent greater than the non-signaling value. It is obvious that notwithstanding the fact that this heavy overload is more or less intermittent, it will, without doubt, materially shorten the life of the oscillator tubes. In power engineering, it would, of course, be considered doubtful practice to subject a generating unit to an overload of from 50 to 400 percent, even tho such a condition did not obtain continuously.

This serious overloading can, of course, be avoided, as is sometimes done, by adjusting the radio frequency oscillating circuit, so that the non-signaling power output has a value con-

[1] "Modulation in Radio Telephony," Proceedings of The Institute of Radio Engineers, R. A. Heising, August, 1921.

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siderably below the normal possible output of the tubes. This means that the amplitude of the non-signaling value of the carrier wave is less than the tubes are capable of maintaining, with the result that the range of the station is materially lessened. In short, to secure 100 percent modulation, and at the same time not seriously overload the tubes, they must be operated at reduced output.

Further, since the modulating tubes in the "constant current" system are of the same capacity as the power tubes, it usually becomes necessary, in order effectively to control the internal resistance of the modulating tubes, to introduce one or more steps of power amplification between the microphone and the modulating circuit. This is true even for tubes having a capacity as low as 50 watts. On the large broadcasting sets employing this system of modulation, a power amplifying tube having a wattage capacity comparable with the power and modulating tubes is used, and has associated with it several steps of amplification involving smaller tubes. The necessity of employing a substantial train of amplifying tubes between the microphone and the modulator tubes is, in and of itself, a serious limitation. Reference will be made to this feature in a later paragraph.

In considering any modulation system, there is naturally involved the question of the relative importance of the non-signaling amplitude of the carrier current, and the variation taking place in this due to the modulation brought about at the transmitting station. For a given amplitude of non-signaling carrier wave which may reach a receiving station, the response in the telephone receiver, is, of course, proportional to the *change in the amplitude of the carrier wave*, this in turn depending upon the modulation at the transmitting station. However, the *actual amplitude of the carrier current* is also an important factor. This is evident when we consider the relation of the amplitude of the non-signaling carrier current to the maximum change which can take place in this current. Even tho complete modulation obtains, the current amplitude cannot have a minimum value less than zero or a maximum greater than twice the non-signaling value. In short, the total change that can occur is $2A$, where A represents the amplitude of the non-signaling carrier current. Obviously, then, if we reduce the output of our tubes to avoid excessive overloading, the value of A will be correspondingly reduced, with the result that the maximum change, $2A$, will be lessened and the signal strength accordingly diminished. By the same reasoning it is also evident that one may, if de-

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sired, secure the same signal strength by utilizing a somewhat greater amplitude of non-signaling carrier wave and a lesser degree of modulation. Indeed, for other reasons, it is better operating practice not to adjust the equipment to give 100 percent modulation. It will thus be seen that the *absolute value* of the non-signaling carrier current is a factor of importance, as well as the *change* in its value. This point has been a matter of considerable debate, and it possesses both general and special interest in a discussion of the limitations of the "constant current" system of modulation.

Grid-Leak Method

In order to provide a system which would not seriously overload the tubes as a result of modulation taking place, and which would at the same time reduce the total number of tubes required to effect modulation, as well as give a higher ratio of distance covered to total watts consumed, a system has been devised which in actual practice has given very gratifying results. This system falls under the general heading of types of modulation, known as the control of generation principle, or, more popularly, grid modulation.

The simple method of introducing the secondary of a modulation transformer in the grid circuit of a radio frequency power organization is well known. Such a system, however, has not been found to be entirely satisfactory for use in sets utilizing more than a few watts, and then only with high impedance tubes.

In the system to be described, and which is shown in diagrammatic form in Figure 1, the usual grid leak resistance is replaced by a three-electrode tube, and the plate-to-filament resistance of this grid-to-leak tube is controlled by means of the voice thru the usual modulation transformer connected to its grid. In this system the control tube functions as a variable resistance. The system may be utilized in connection with generating organizations, other than the well-known circuit outlined in the drawing.

The author independently worked out this system of modulation during August, 1920. It later developed that the De Forest laboratories were apparently doing some work along the same line at about the same time, and a patent[2] has recently been issued to C. V. Logwood covering a balanced generating circuit which incidentally incorporates a modulating scheme similar in certain respects to the one outlined in this paper. In the September

[2] U. S. Patent 1,449,834, filed July 2, 1921. Assigned to the De Forest Telephone and Telegraph Company.

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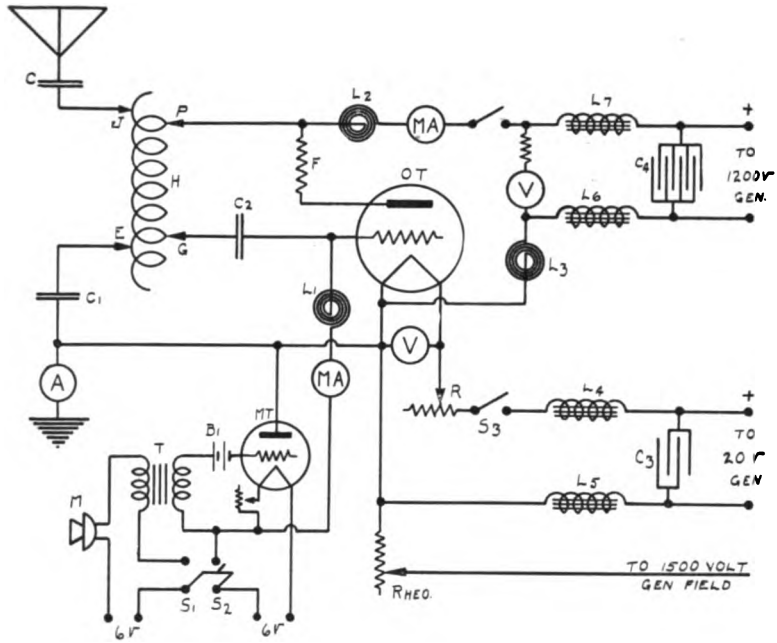

FIGURE 1—Schematic Wiring Diagram of Typical Radiophone Transmitting Circuit Incorporating Grid Leak Method of Modulation

number of "The Radio Review" for 1920, there appeared an abstract of an earlier account by Beauvais of a somewhat similar modulation scheme for use in connection with guided wave communication. However, so far as we are aware, the author is the first to develop the method to the point where practical and successful engineering results have been secured.

THEORY OF OPERATION

Before passing to a description of the actual radiophone transmitting units incorporating the grid-leak method of modulation, we shall briefly consider the theory of its operation.

Again referring to Figure 1, it will be evident that, for a given value of grid condenser C_2, the direct current potential of the grid of the oscillating tube will be determined by the magnitude of the inductive reactance in the anode-grid circuit, and also by the value of the grid leak, the latter consisting of the plate-filament circuit of the modulating or control tube *M T*. If the value of this resistance changes, the direct current potential of the grid of the oscillating tubes will correspondingly change and control thus be effected.

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Measurements made by means of a special electrostatic voltmeter having negligible intrinsic capacity show that, in general, as the grid leak resistance is decreased and the grid leak current correspondingly increased, the potential difference between the grid of the oscillator and the grounded side of the filament increases. In other words, the grid becomes more negative with respect to the filament. These variations in the grid potential result in corresponding variations in the effective alternating current output of the power tube.

The oscillogram shown in Figure 2 illustrates the relation of the grid or control current to the alternating current output. In securing this record an alternating current of small magnitude was passed thru the primary of the modulation transformer.

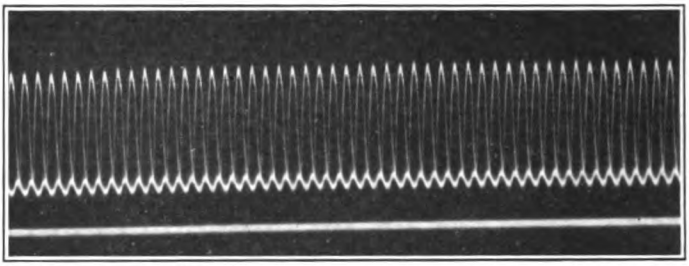

FIGURE 2—Oscillogram Showing Relation of Grid Leak Current to Alternating Current Output. Alternating Current in Primary of Modulation Transformer. Upper Curve Grid Leak Current

The upper curve shows the grid leak current, and the lower curve the corresponding radiation current as picked up and rectified in a closed resonant circuit placed near the transmitting set. Figure 3 shows the phase relations when voice control obtains.

When using a tube, having a static characteristic shown in Figure 4 as an oscillator, the constants are so adjusted that the

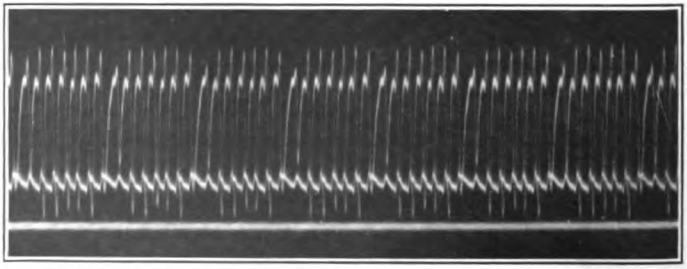

FIGURE 3—Oscillogram Similar to Figure 1, Except Voice Modulation Obtains

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grid of the oscillator has a negative potential of the order of 350 to 700 volts with respect to the filament, and the grid bias of the tube which functions as a modulator is accordingly adjusted so that its operating point remains within the proper limits. The exact potential value at which the grid of the oscil-

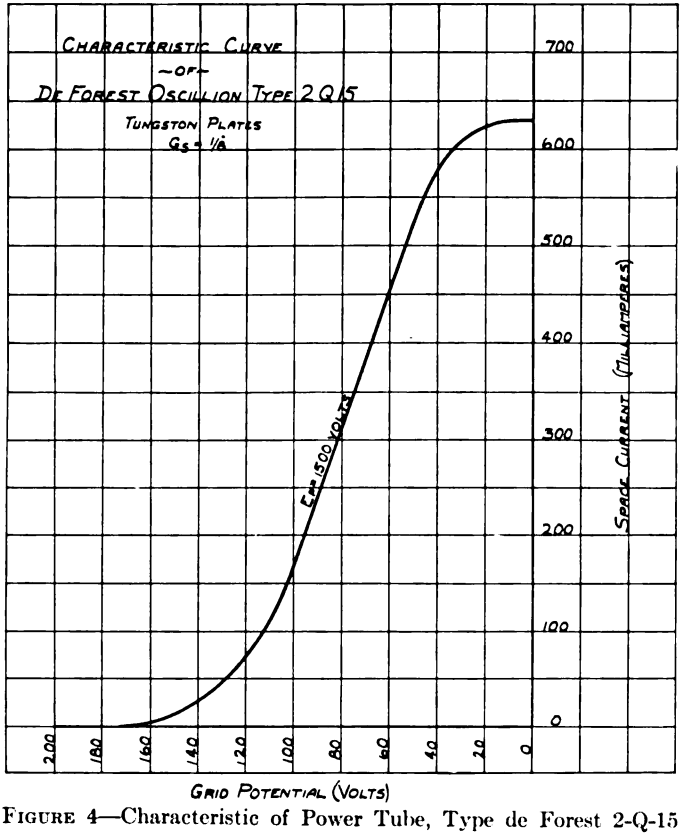

FIGURE 4—Characteristic of Power Tube, Type de Forest 2-Q-15

lating tube is held depends upon the number of power tubes being operated in parallel and upon the relation of the wave length to the antenna constants. In practice the adjustments are usually such that the average value of the oscillator grid potential is decreased when modulation is taking place, voice modulation producing a variation in oscillator grid potential of the order of 100 volts. The adjustments are commonly such that the average signaling value of the antenna current is less than the non-signaling value, the tubes being normally operated at or near their maximum outpot.

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The characteristics of the tube used for effecting modulation by this method must obviously be of such a nature that the tube will withstand the potential developed between the grid and filament of the oscillator: it must also be able to dissipate, when in a non-oscillating condition, the heat developed by the grid-leak current.

Figure 5 shows a family of static curves for the type 1-Q-15 tubes used as modulators in the broadcasting sets, and Figure 6 the corresponding characteristics of the type D tube used as a modulator in the type 1-T sets.

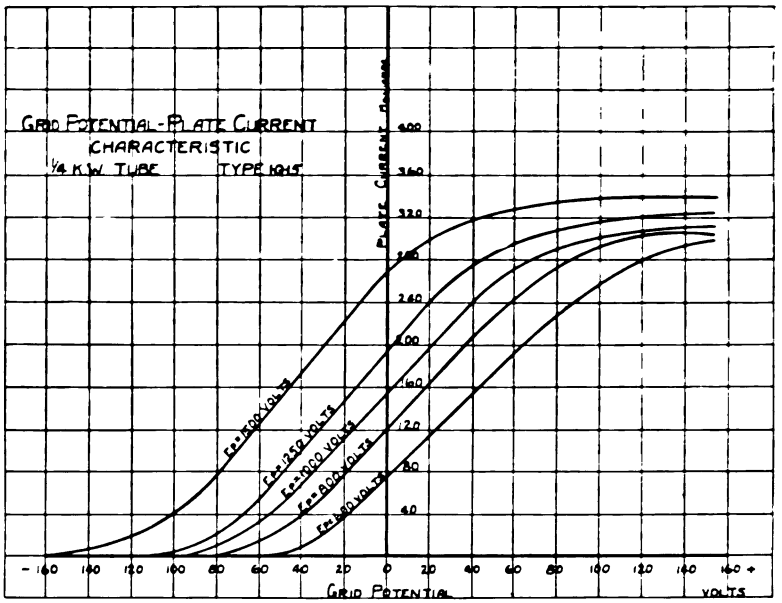

FIGURE 5—Characteristic of Modulator Tube, Type de Forest 1-Q-15

DESCRIPTION OF NEW EQUIPMENT

Two of the several types of actual equipment incorporating the grid-leak method of modulation, and which are in commercial operation, are shown in Figures 7 to 10, inclusive. The type 4-T units are used chiefly for broasdcasting purposes, and the type 1-T for private commercial communication.

The 4-T type utilizes 4 De Forest tubes, type 2-Q-15, as oscillators, and 2 De Forest type 1-Q-15's as modulators. The power tubes are usually operated at an anode potential of 1,800 volts, and when drawing a total plate current of 0.6 to 0.7 ampere will develop from 10-12 amperes in an antenna having average

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broadcasting characteristics, the output being approximately 750 watts. The grid-leak current is of the order of 125 milliamperes. Both the power and modulator tubes are operated at a constant filament potential of 15 volts, each tube being provided with a voltmeter. The plate circuit of each power tube is fused, and the filament circuit of the individual tubes may be opened by means of switches located at the lower edge of the power tube panel. This feature, combined with the adjustable inductance

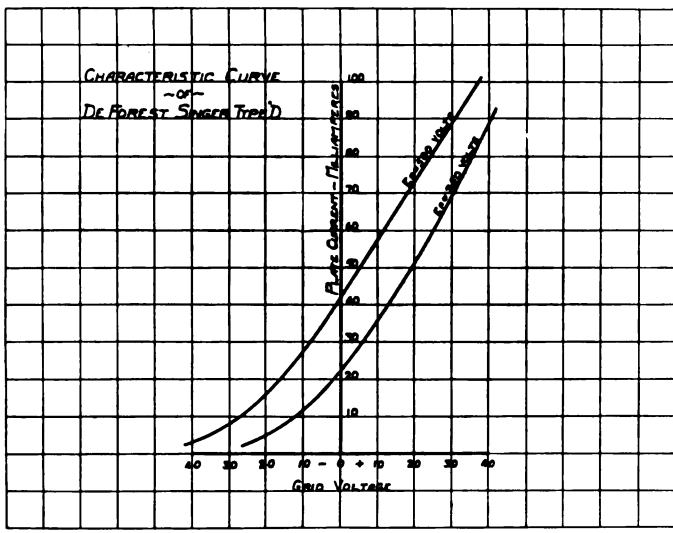

FIGURE 6—Characteristic of Modulator Tube, Type de Forest D

switch controlling the external plate impedance, makes it possible to cut out a given power tube without shutting down the set. This is a particularly valuable feature in broadcasting work. If a power tube goes out of commission during the rendition of a number in the studio, the operator at the board adjusts the plate impedance and proceeds without interrupting the transmission. If desired, he may adjust the circuit constants so that the remaining tubes will temporarily carry the full load, and thus maintain the output of the station at its normal value.

In addition to the usual anode voltage, space current, and radiation meters, a grid-leak current meter is provided, the latter serving as a modulation or control indicator.

Direct current power for these transmitting sets is supplied by a three-unit motor generator outfit consisting of a 2,000-volt, 2-commutator dynamo and a 20-volt machine for supplying the

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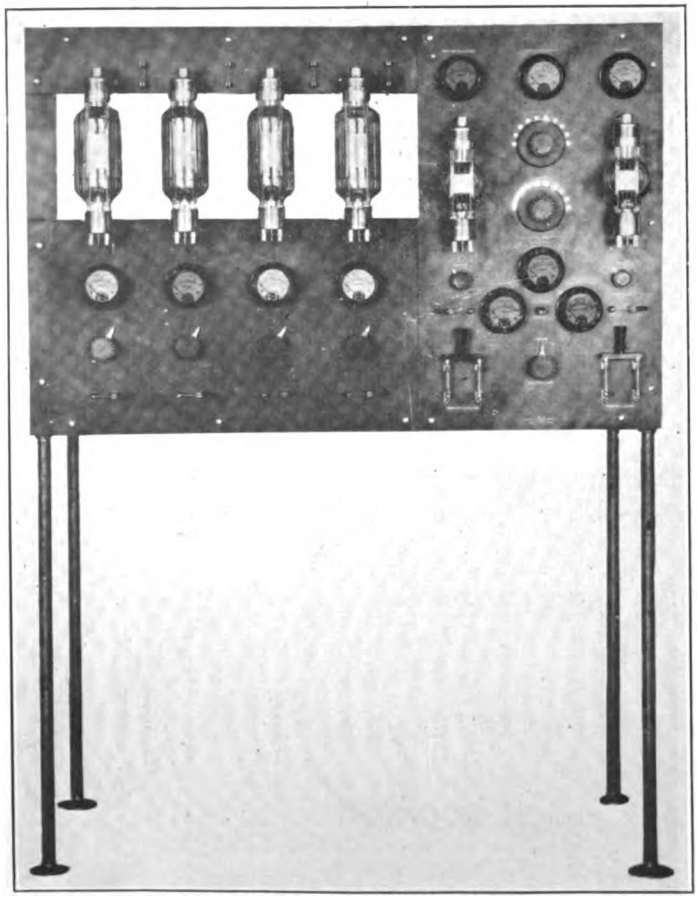

FIGURE 7- Photograph of Radiophone Transmitter, Type 4-T, Front View

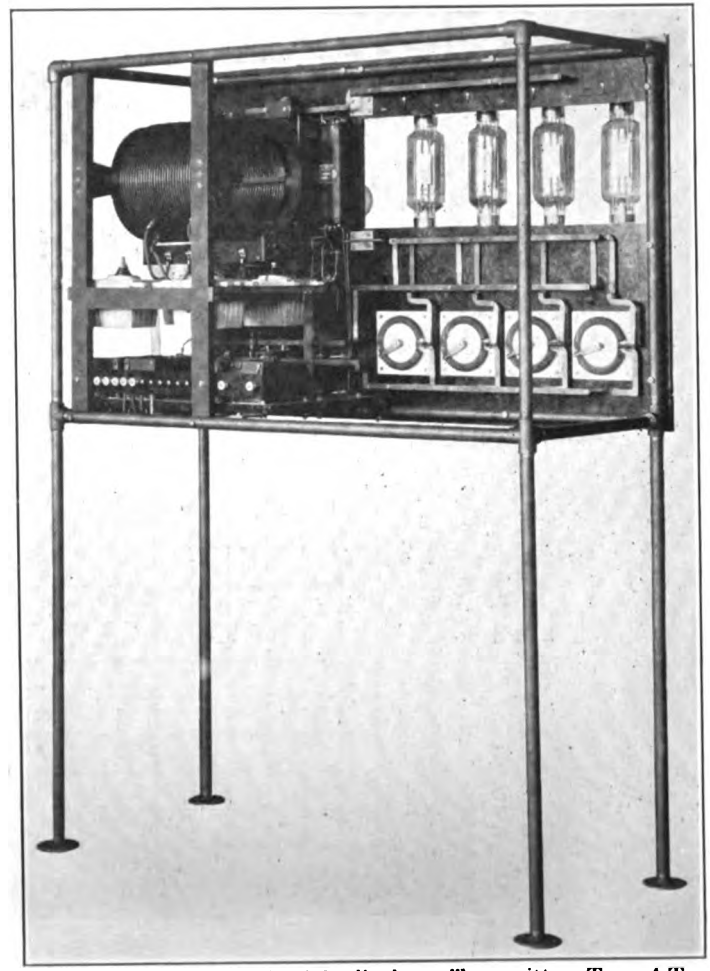

FIGURE 8 Photograph of Radiophone Transmitter, Type 4-T, Back View

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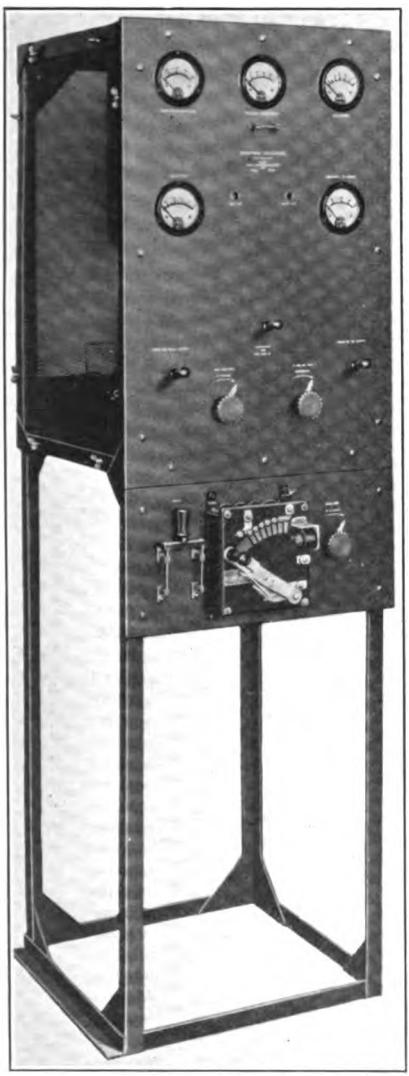

FIGURE 9—Photograph of Radiophone Transmitter, Type 1-T, Front View

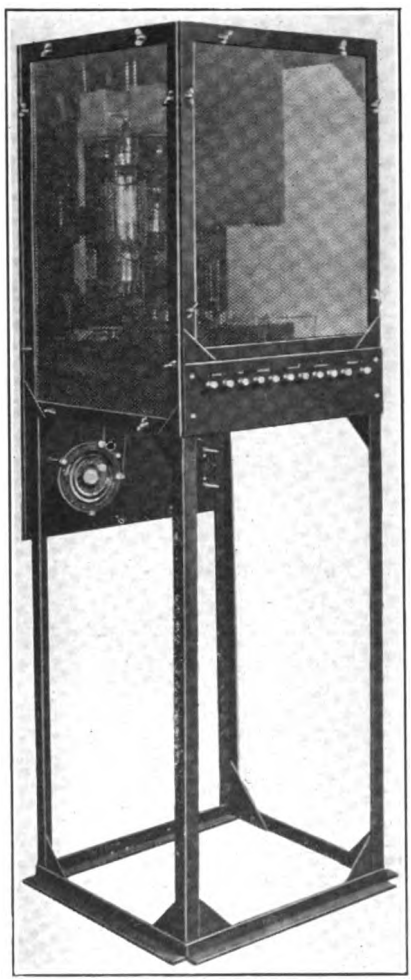

FIGURE 10—Photograph of Radiophone Transmitter, Type 1-T, Back View

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filaments of the power tubes, these units being directly coupled to a driving motor of suitable capacity.

An interesting bit of radio history was written last fall, when the first one of these broadcasting sets to be installed was operated for eight hours daily during a period of two weeks at the time of the Canadian National Exhibition, without suffering an interruption.

The 1-T transmitters do not differ essentially from the type just described, except in size. This type utilizes a single De Forest 2-Q-15 tube as oscillator and a De Forest type "D" tube as modulator. This transmitting unit has a normal output of 150 to 200 watts, the antenna current being of the order of 5 amperes.

Comparison of Efficiency

This paper is entitled "An Improved System of Modulation," and the justification for such a caption will be evident from an examination of the following table:

To Deliver 500 watts to Antenna	Constant Current Method	Grid Leak Method
Power consumed by oscillator tubes	1,040 watts	1,080 watts
Power consumed by modulator tubes	312	none
Power consumed by power amplifier tubes	400	none
Total power consumption	1,752	1,080

In preparing the above table the data for the constant current system were taken from published statements regarding a well-known and widely used commercial type of broadcasting equipment.

In explanation of the third item in the table under the grid-leak method, it may be said that when using an ordinary microphone no amplification whatever of the voice currents is required. When, however, the comparatively insensitive pick-up devices

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commonly employed in broadcasting are used, a 5-watt power tube is utilized as a speech amplifier. Obviously this does not add materially to the total power consumed. In making the above comparison, reference was not made in either case to the number of steps of voltage amplification employed between the pick-up and the transmitting set, for the reason that local circumstances govern this factor in both cases. However, it may be said that two steps of voltage amplification have, to date, met all requirements.

In the last analysis the convincing evidence as to the comparative merits of any system of radio communication is the transmission ratio, that is, the ratio of miles covered to total watts consumed by the equipment. Engineering tests made for the purpose of comparing the grid leak system of modulation with other methods show that the mile-watt ratio is entirely comparable, if not greater, in the case of the new system. One of the several Canadian broadcasting stations employing this system of modulation is located at Regina, Saskatchewan. The owners of that station state that a conservative average estimate of the night range would be one thousand miles (1,600 km.), and a day range of four hundred miles (640 km.). They add the statement that recently the afternoon broadcasts were heard every day for two weeks in Seattle, the distance being approximately eight hundred miles (1,280 km.), and this across the mountains. The total anode input to the set did not exceed 600 watts. It should, however, be said that conditions for radio communication in Middle and Western Canada are probably somewhat more favorable than in the eastern provinces. A night transmission ratio of 0.9 would probably be a more fair figure. That is, for every 1,000 watts consumed by the transmitting equipment, 900 miles can be successfully covered under average reception conditions.

No corresponding figures are available for the equipment using the constant current system, but judging from various published reports, and as well as from actual personal observations on the transmission from those sets, it would appear that the average night transmission ratio would not exceed 0.6. In making the above comparison we refer to the night ratio, because the greater part of the broadcasting is done then, and it is thus possible to secure more data under those conditions. It is fully appreciated that it is extremely difficult to make reliable quantitative comparisons in regard to radio transmission, but the figures are, in the case of the new system, conservative, and would

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appear to indicate that it is in fact an improved system of modulation.

The ideal outlined at the beginning has not yet been attained, but an effective system of voice control has been developed which gives faithful modulation, and which materially reduces the number of large capacity tubes required for efficient radiophone operation.

SUMMARY: After describing the commonly employed absorption and constant current systems of radio telephone modulation, the author discusses a system of modulation wherein the resistance in the grid circuit of the power oscillator tubes is vocally varied, this resistance being itself the plate circuit of a suitable vacuum tube. Operating data on sets embodying this method are given.

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DISCUSSION

C. V. Logwood (by letter):* I would like to ask Dr. Culver if, in calculating the efficiency as outlined in his table of the relative power input to output as compared to the constant current method, he took into consideration the adjustment for grid potential.

In my experiments in the development of this system for the Canadian Independent Telephone Company in 1922 and the De Forest Radio Telephone and Telegraph Company in 1921, as well as my earlier work in 1917,† I have found that considerable grid current flow is very essential for modulation depth and clarity. This grid current flow must pass thru the two power tubes used as modulators with a negative biasing battery of 45 volts, in order that the grid current flow from the power tubes does not exceed the safe current flow from the grids, which I believe is 40 milliamperes per power tube. It would seem to those interested in this subject that considerable power is lost in overcoming this biasing battery voltage which performs two things: amplification and a check for the grid current.

I ask this question because one can secure maximum radiation when the grid flow from each 2Q-15 power tube does not exceed 3 milliamperes thru the proper grid leak resistance. For clarity and depth of modulation it is absolutely essential to have the full grid current flowing from each power tube and this, I believe, will lower the efficiency by 200 watts.

I would like to know if Dr. Culver has taken into consideration the relative percentage of modulation of the circuit described to the constant current method when both are modulating at a given percentage, for instance, 25 percent. That is, will it require greater power amplification in watts for 25 percent modulation using the constant current method than that which is required to modulate at the same efficiency with the parallel oscillating circuit as described in his paper?

From my own conclusion I am quite sure that the parallel oscillating circuit is not much more efficient than the constant current method after all calculations are checked up, granting an equal degree of clarity.

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*Received by the Editor, June 27, 1923.

†C. V. Logwood, United States patent number 1,397,432.

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RADIO FREQUENCY TESTS ON ANTENNA INSULATORS*

By

W. W. Brown

(Radio Engineering Department, Alternator Section, General Electric Company, Schenectady, New York)

With the installation of 200 kilowatt Alexanderson alternators in the New Brunswick, New Jersey and Marion, Massachusetts, radio stations, it was found that the insulators previously used in the antennas at these stations were unsuited to the new conditions. There were a number of different types of insulators available at that time, but very little information was available on their characteristics for radio frequency, high voltage, continuous wave use.

Insulators for use on radio frequency continuous wave circuits should be so designed that the dielectric flux density is very low as compared with the densities permissible in insulators for 60-cycle circuits. The reason for this is that the dielectric hysteresis loss for a given flux density is nearly proportional to the frequency for the best insulators, and the power factor[1] in some less perfect dielectrics increases as the square or higher power with the frequency. A type of insulator, the limitation of which on a 60-cycle circuit might be flashover or even puncture, might be unsuitable for use on a radio frequency circuit of a much lower voltage, because of heating of the dielectric.

In designing an insulator that will have a low dielectric loss at radio frequency, the following conditions need be considered:

1. The dielectric hysteresis loss is proportional nearly to the square of the flux density.

2. The flux density decreases with increasing distance between electrodes.

3. The flux density is directly proportional to the specific inductive capacity of the dielectric.

*Received by the Editor, February 14, 1923. Presented before The Institute of Radio Engineers, New York, March 7, 1923.

[1] E. F. W. Alexanderson, "Dielectric Hysteresis at Radio Frequencies," Proceedings of The Institute of Radio Engineers, June, 1914.

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In considering these conditions, the desired insulator should have:

1. low flux density,
2. long distances between electrodes, and
3. be of a material which has a low specific inductive capacity.

The type of antenna insulator that most nearly fulfils these conditions is a cylindrical rod or tube the length of which is several times its diameter. This type of insulator with a dielectric of porcelain is used almost exclusively for high voltage radio antennas.

An insulator composed of a porcelain rod 2 inches (5.08 cm.) in diameter and 20 inches (50.8 cm.) long with a metal cap on each end, if subjected to high voltage continuous wave at radio frequency, would exhibit a temperature rise of the porcelain rod much higher near the fittings than near the middle. This is due to the fact that the dielectric loss is proportional nearly to the square of the density, and the density is greatest at the fittings.

The arrangement of an antenna insulator with reference to the supporting structure and the antenna proper may be such that the dielectric density at one end of the insulator is greater than at the other end. The density usually is greatest at the end next to the antenna and lowest at the grounded end. (Under certain conditions, the reverse of this relation exists.) This is because of the fact that one end of the insulator may be shielded by the surrounding structure to such an extent that the dielectric flux, which leaves the unshielded end, reaches the shielded end thru the surrounding structure and thereby reduces the density thru the dielectric at the shielded end.

This suggests the possibility of providing an electrostatic shield on one or both ends of this type of insulator to reduce the density thru the dielectric, and this has been found to be entirely feasible. By the use of these shields, the radio frequency voltage rating of insulators of this type may be greatly increased and the dielectric losses reduced.

Insulators of this type, with well designed fittings and shields, have a relatively small dielectric loss and are very satisfactory under dry weather conditions. Under wet weather or salt spray conditions, the surface leakage is high and various arrangements of shields have been provided to protect the surfaces.

A series of tests were made in Schenectady, for the Radio Corporation of America, to determine primarily the characteristics of the various available types of antenna insulators. Stand-

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ard types of insulators, for other than antenna circuits, were tested to determine their suitability for operation with radio frequency, continuous wave transmitters. Subsequent tests have been made at the Radio Corporation's high power stations. Power for all these tests was supplied by 200 kilowatt Alexanderson alternators at frequencies between 18,000 and 28,000 cycles per second.

Test Equipment at Schenectady

Figure 1 shows diagrammatically the circuits used at Schenectady to obtain the high voltage at radio frequency continuous waves.

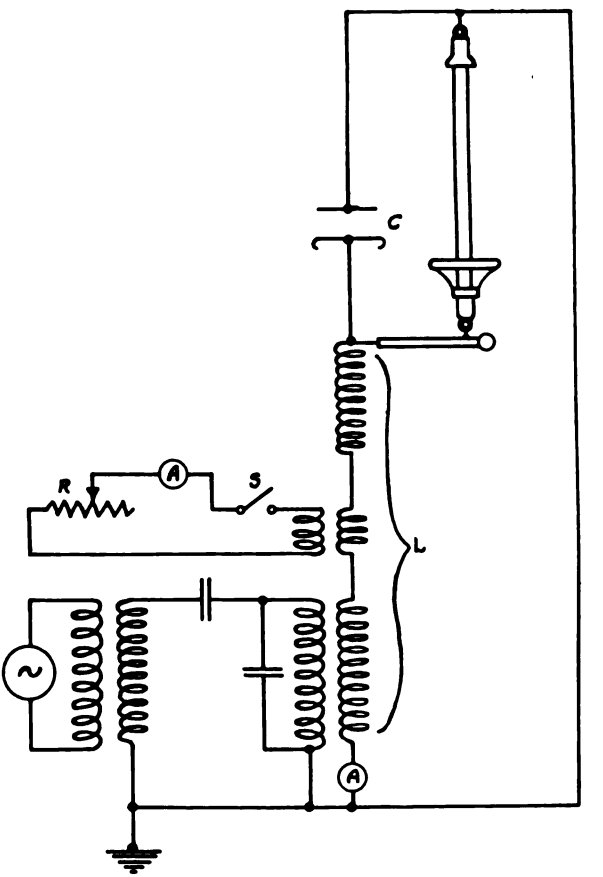

Figure 1

A 200-kilowatt Alexanderson alternator, thru suitable transformers and tuning condensers supplied energy to the resonant circuit *L*

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and C shown in the diagram. The total inductance in the resonant circuit was 84.5 henrys, which has an inductive reactance of 11,500 ohms at 21,700 cycles. The value of C, the capacity reactance of which is 11,500 ohms at 21,700 cycles, is 0.000637 mf. The area of the lower or high voltage condenser plate was 384 sq. ft. (35.7 sq. m.). Insulators under test were suspended from the steel framework of the building. A 4-inch (10.16 cm.) diameter metal tube with a 10-inch (25.4 cm.) diameter sphere on the outer end conducted the high voltage from a point between the L and C of the resonant circuit to the insulator under test.

The test voltage was calculated by multiplying the measured current in the ground side of the resonant circuit by the measured inductive reactance L at the operating frequency.

The circuit containing resistance R was used to determine the loss in the insulator under test. The principle of measuring the insulator loss by this method is the substitution, for the insulator under test, of an artificial load circuit that will absorb the same energy from the resonant circuit that is absorbed by the insulator. The method of making these measurements was as follows: With the test insulator in circuit, frequency of the power supply was varied thru resonance and the maximum resonant current noted. The test insulator was then removed from circuit, under which condition the maximum resonant current was higher than with the test insulator in circuit, other conditions remaining unchanged. Switch S was then closed, and the calibrated resistance R was varied until the maximum resonant current was the same as with the test insulator in circuit. Under this condition, the measured current in the auxiliary circuit, squared, times the ohmic resistance was an indication of the watts loss in the insulator.

The loss in porcelain tube insulators under dry conditions was too low to measure by this method at voltages which would have been excessive for the same insulator under rain conditions. The loss in large insulators at high voltage, under rain conditions, was readily determined by this method.

Figure 2 is a photograph which shows part of the test apparatus. The condenser plate mounted on top of the inductance coil is in a fixed position. The grounded wire screen directly above the fixed condenser plate was movable and provided means to obtain resonance in the circuit over a range of frequency.

A precipitation of approximately 0.2 inch (0.5 cm.) per minute, Schenectady city water having a resistance of 3,400 ohms per centimeter cube, was used in making the rain tests.

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Resistance of rain water varies between 10,000 ohms per centimeter cube in smoky atmosphere to 70,000 ohms per centimeter cube in clean atmosphere.

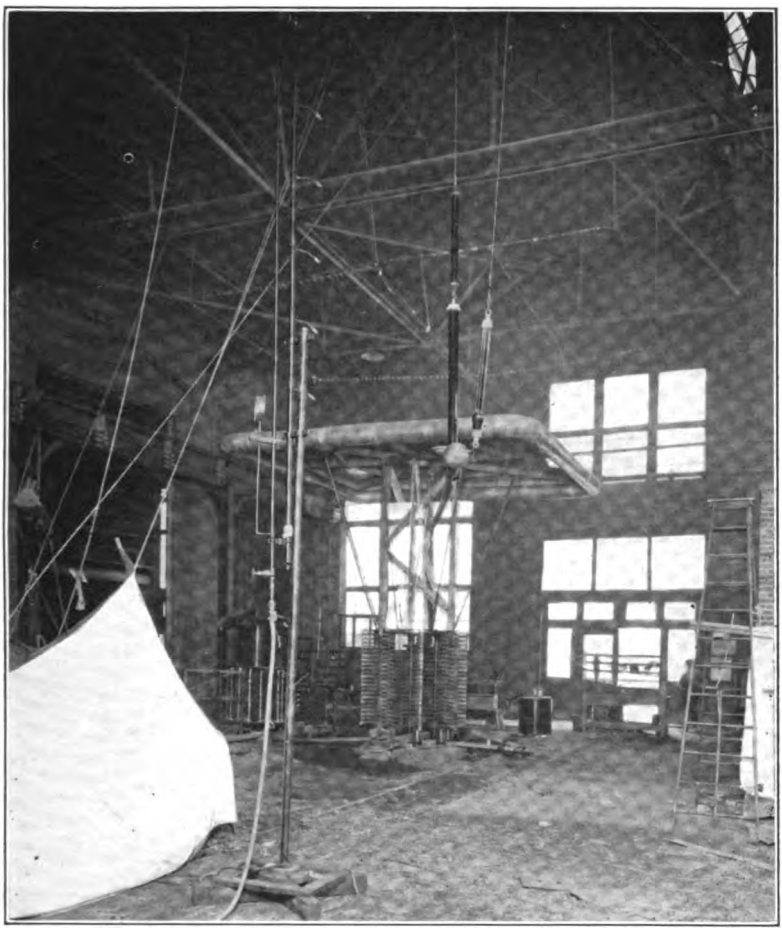

FIGURE 2

TEST DATA

Figure 3-A shows the heating characteristics under both dry and rain conditions of a porcelain tube having an outside diameter of 2 inches (5.08 cm.) and a clear length of 32 inches (81.4 cm.) between metal fittings. Figure 3-B shows comparable data on the same insulator, but with an electrostatic shield on the high-tension—lower—end. The effect of the shield is to re-distribute the losses along the length of the tube and to lower the flashover under rain conditions from 138 kilovolts to 125 kilovolts.

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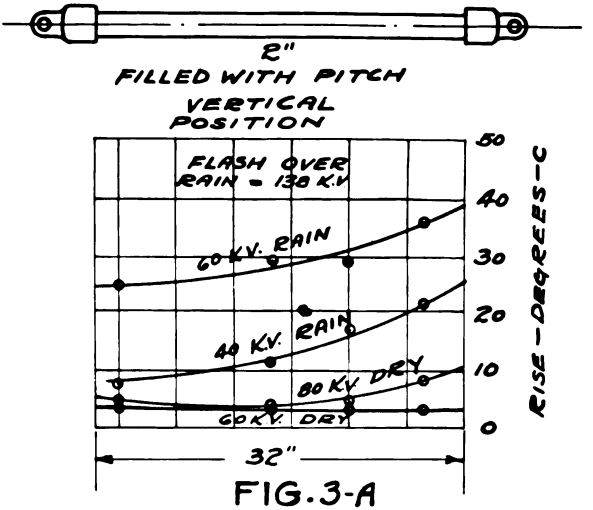
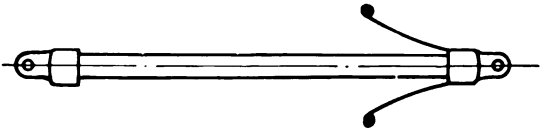


FIG. 3-A



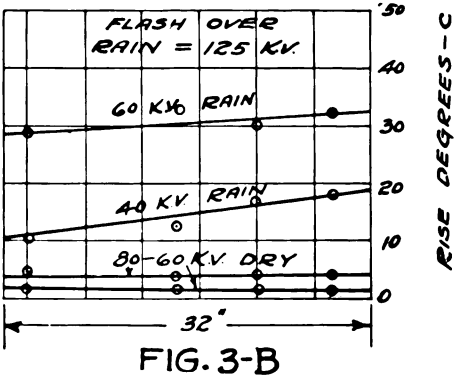


FIG. 3-B

FIGURE 3

The method of obtaining these data was to apply a definite voltage for 30 minutes, the length of time for the temperatures to become practically constant. The voltage was then removed, a strip of felt attached lengthwise to the porcelain tube and thermometers placed thru holes in the felt with the thermometer bulbs against the porcelain.

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Figure 4-A shows heating data under dry and rain conditions on a 2⅜ inch (6.02 cm.) by 3½ inch (8.89 cm.) diameter porcelain tube with a clear length of 30 inches (76.2 cm.) A 20-inch (50.8 cm.) diameter cast aluminum electrostatic shield was attached to the high voltage end. The insulator was in a vertical position.

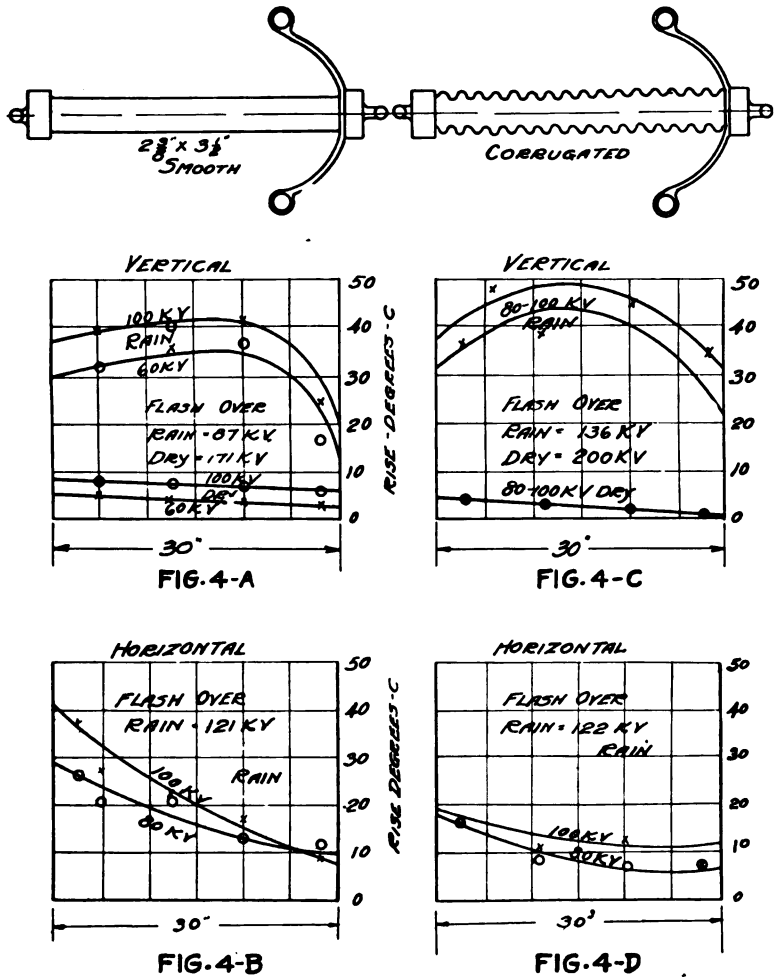

FIGURE 4

Figure 4-B shows the data on the same insulator under rain conditions, but with the insulator in a horizontal instead of a vertical position. The temperatures under dry conditions, also under rain conditions, in a horizontal position, indicate the pro-

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portions of the shield and the length of the insulator are such that the losses in the grounded end are much greater than in the high potential end. The low flashover of 87 kilovolts under rain conditions with the insulator vertical, as compared with flashover of 121 kilovolts with the insulator horizontal, indicated an advantage in breaking up the water stream.

Figures 4-C and 4-D show the heating data on an insulator of the same general dimensions as the insulator shown in Figure 4-A, but having corrugations instead of a smooth surface. The indicated improvements in the corrugated tube, as compared with the smooth tube insulator are: higher flashover dry; higher flashover under rain conditions in a vertical position, and lower losses under rain conditions with the insulator in a horizontal position. Higher losses are indicated under rain conditions in the corrugated tube than in the smooth tube with the insulator in a vertical position. Since low losses are of greater importance than high flashover, the lower losses in a horizontal position are counteracted by higher losses in a vertical position with a resultant small, if any, improvement by corrugations.

Figure 5 shows heating data on a 2 inches (5.08 cm.) by 3½ inches (8.89 cm.) tube insulator with a clear length of 40 inches (101.6 cm.) and with a 20 inches (50.8 cm.) diameter electrostatic shield.

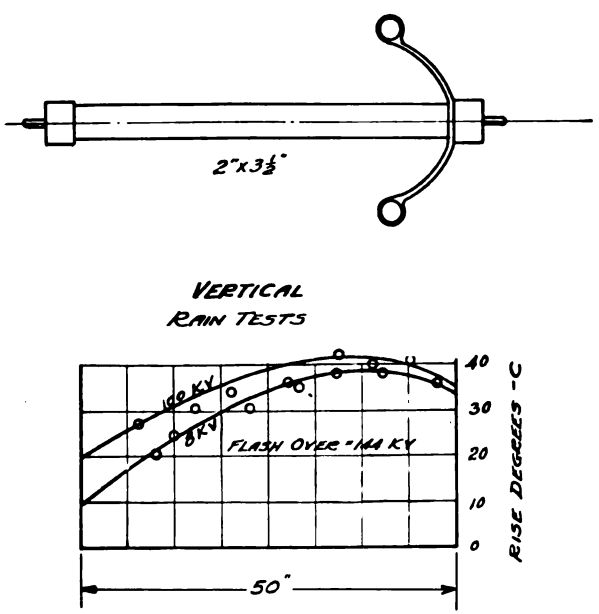

FIGURE 5

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Figure 6 shows heating data on a 2 inch (5.08 cm.) by 3½ inch (8.89 cm.) tube insulator with a clear length of 50 inches (127 cm.) and without the electrostatic shield. The effect of the physical position of the insulator is shown.

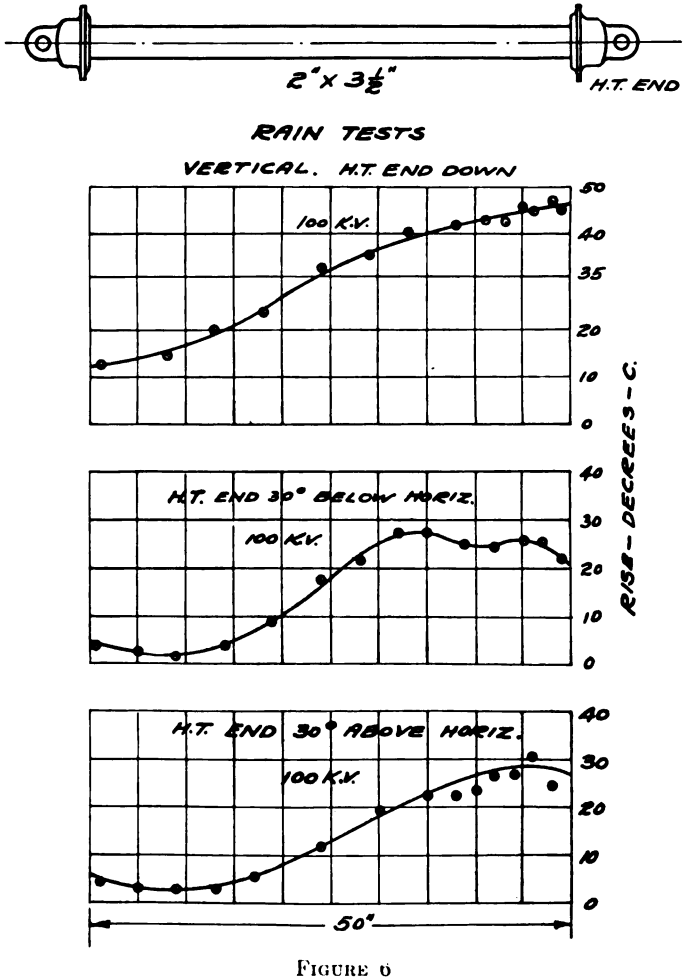

FIGURE 6

Figure 7 shows heating data on a 2⅜ inch (6.02 cm.) by 3½ inch (8.89 cm.) tube insulator with a clear length of 60 inches (152.4 cm.) and with the 20 inch (50.8 cm.) diameter electrostatic shield. The effect of the physical position of the insulator is shown. The loss in this insulator in a vertical position under rain conditions is estimated to be more than 500 watts

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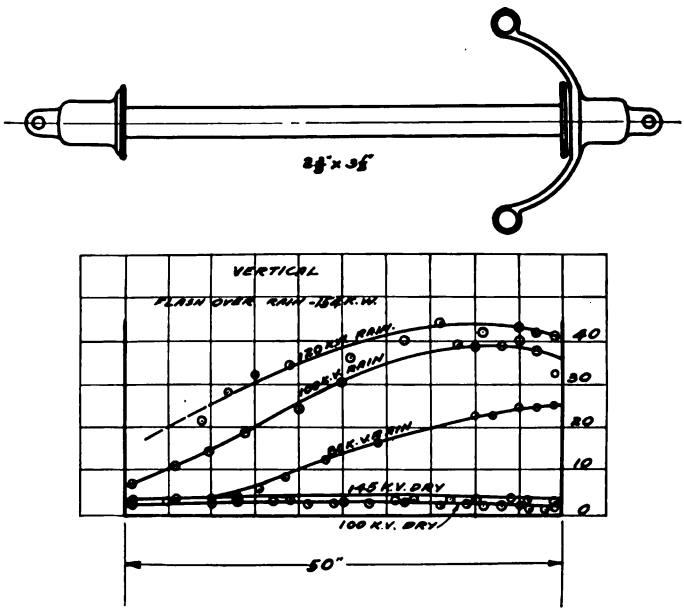

FIGURE 7

at 100 kilovolts. This estimate is based on the measured loss in the insulator shown in the next Figure.

Figure 9 shows the possibility of distributing the loss along the length of the 60-inch (152.4 cm.) porcelain tube by the use of metal electrostatic-rain shields attached to the tube. By placing these shields in a definite position along the tube, it is possible greatly to reduce and improve the distribution of losses along the entire length, under rain conditions, without impairing the distribution under dry conditions. The highest temperature rise at 100 kilovolts with the electrostatic shields on the tube is 15 degrees; with the cast shield alone is 48 degrees. The flash-over is practically the same with and without the electrostatic-rain shields. The measured loss of 360 watts, as shown in the bottom graph in Figure 9, was the basis used to estimate the loss at 100 kilovolts under the conditions shown in Figure 8.

Figures 10 and 11 show the effect of "breathers" in the metal fittings. These fittings are attached to porcelain tubes with cement which contains moisture. The cement is dried by placing the complete insulator in an oven. With the tube sealed tightly at both ends, it appears that moisture is trapped inside the tube and produces additional losses in the insulator, as indicated by the temperature data in Figures 10 and 11. It was determined

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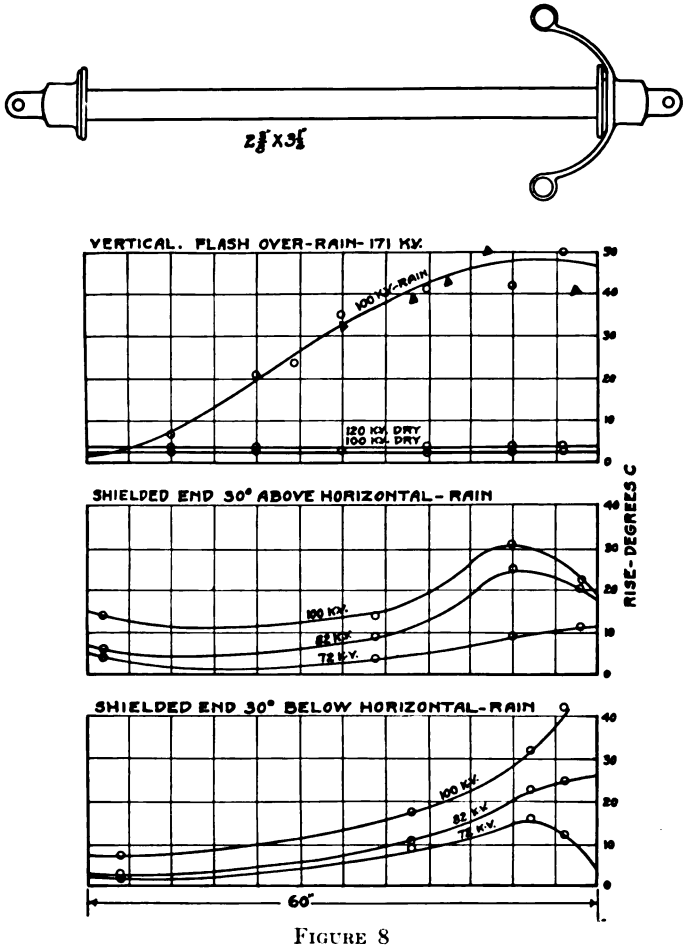

FIGURE 8

conclusively that the lower temperatures obtained with "breathers" were not due to circulation of air thru the tube. After the air inside the tube has been dried, it appears to make but little difference whether the "breathers" are open or closed. Ingenious methods have been devised by the manufacturers to provide the insulators with "breathers" that will permit the escape of moisture but prevent water from entering.

TUBULAR INSULATORS WITH SHIELDS AT THE RADIO CORPORATION OF AMERICA'S HIGH POWER STATION

Figure 12 shows an arrangement of salt and rain shields, designed by Mr. J. L. Finch, of the Radio Corporation of America,

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to prevent rain and salt spray from depositing on the porcelain of the insulator. This was designed to meet an unusually severe

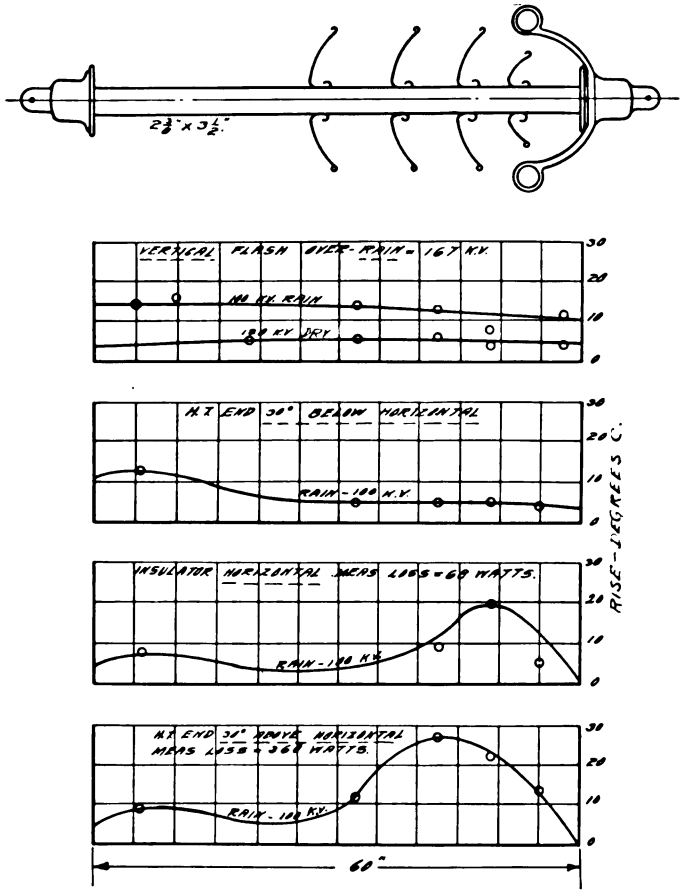

FIGURE 9

condition of salt spray at the Radio Corporation's station at Kahuku, Hawaiian Islands. From Mr. Finch's description of the conditions there, the salt spray deposits a coating of salt which does not appear harmful when the coating is dry. Under rain conditions, the deposit becomes conducting and causes the insulators to have high leakage and flashover from end to end at less than 100 kilovolts. There were no indications of corona or any sign of failure at the time the insulator with sample shields was put in service, and the insulator has now been in service for several months.

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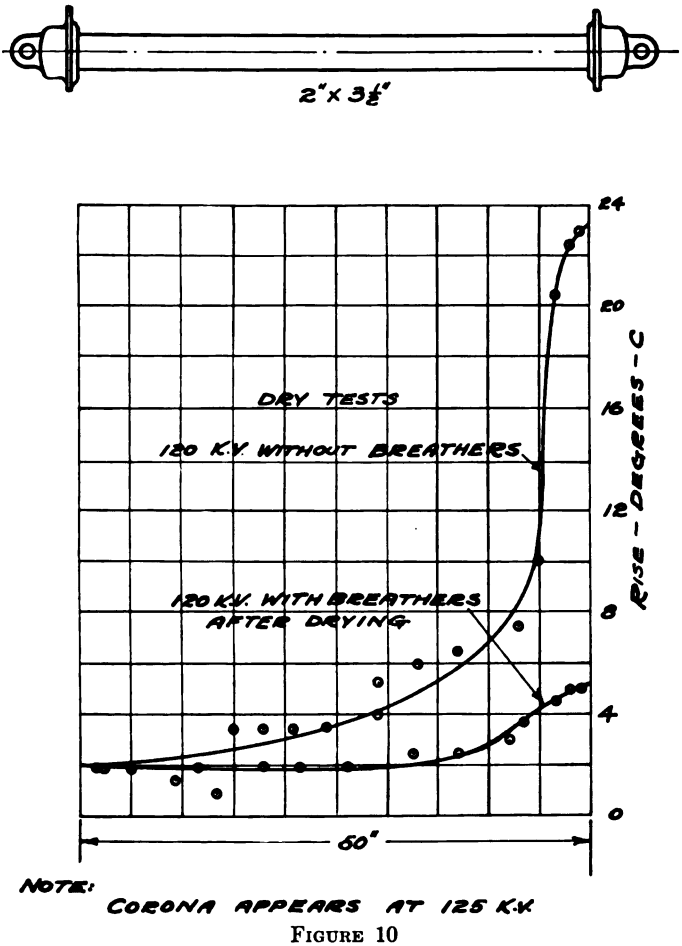

FIGURE 10

Figure 13 shows an arrangement of rain and electrostatic shields on antenna insulators as used at the Radio Central station. In this arrangement, there are two insulators in series between each antenna conductor and grounded support. Each of these insulators has a 40-inch (101.6 cm.) clear length of porcelain and each is fitted with a cast aluminum corona shield on the bottom and a formed aluminum rain-electrostatic shield on top. The distribution of voltage across these two insulators in series was measured by Mr. C. W. Hansell, of the Radio Corporation, and found to be approximately 75 percent of the total voltage across the unit on the high voltage side.

Figure 14 shows another arrangement of electrostatic-rain

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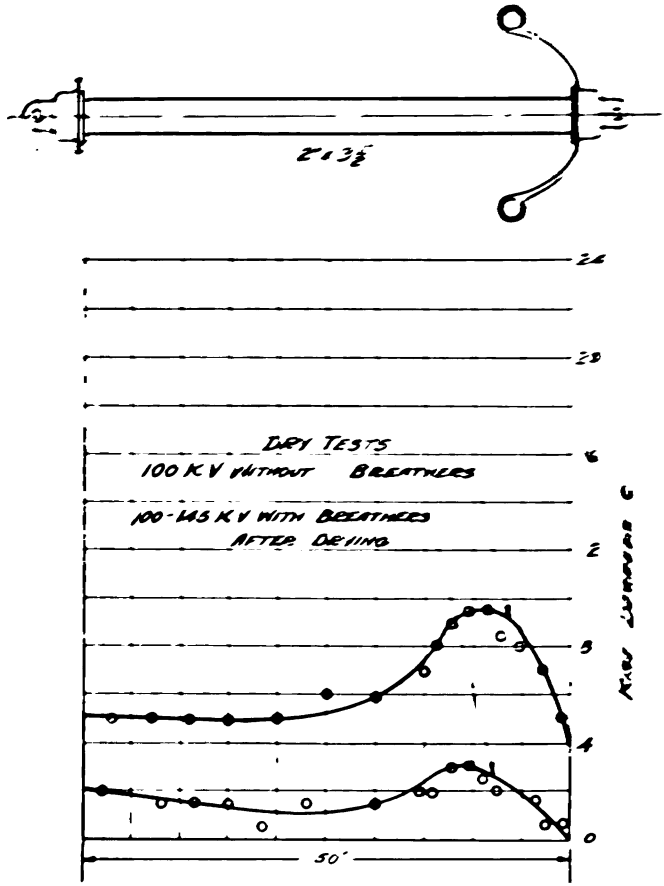

FIGURE 11

shields as used at Radio Central station on insulators having a 60-inch (152.4 cm.) clear length of porcelain.

GENERAL DATA

Figure 15 shows heating data on an insulator which has an

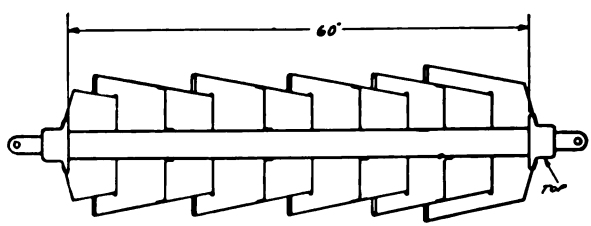

FIGURE 12- Salt and Rain Shield for Antenna Insulator

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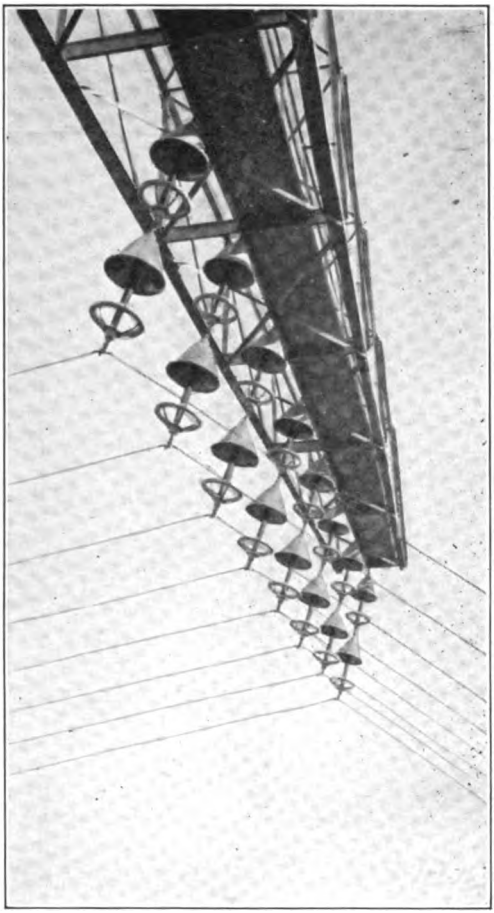

FIGURE 13

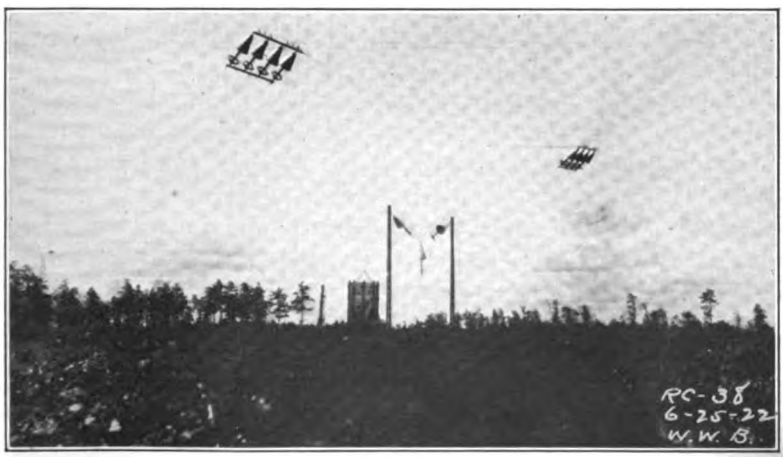

FIGURE 14

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internal electrostatic shield as indicated. Under dry conditions there was no appreciable heating to 75 kilovolts; flashover occurs at 154 kilovolts. Under rain conditions there was appreciable temperature rise at 50 kilovolts and flashover occurred at 89.5 kilovolts. The temperatures indicated were obtained after an application of 87 kilovolts for thirteen minutes under rain conditions.

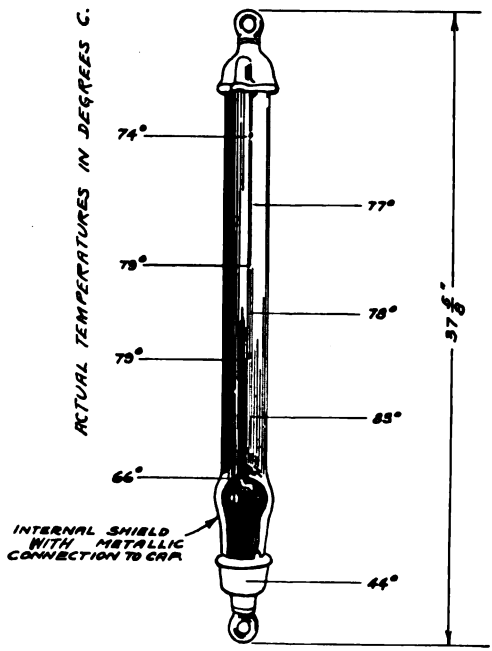

FIGURE 15

Figure 16 shows flashover of the insulator with internal shield under rain conditions.

Figures 17 and 18 show corona, leakage, and flashover values at 100,000 cycles damped wave and at 60 cycles continuous wave under dry and rain conditions on the 60-inch (152.4 cm.) tube type of insulator and the internal shield type.

Figure 19 shows the nature of failure of an insulator composed of a treated rod in the center, surrounded by a porcelain tube, and with the space between the rod and tube filled with pitch. Failure of these insulators at relatively low voltage is believed to be due to moisture in the wood or sharp corners on the metal fittings which start carbonization of the wood. Carbonization once started continues lengthwise thru the rod—not on the sur-

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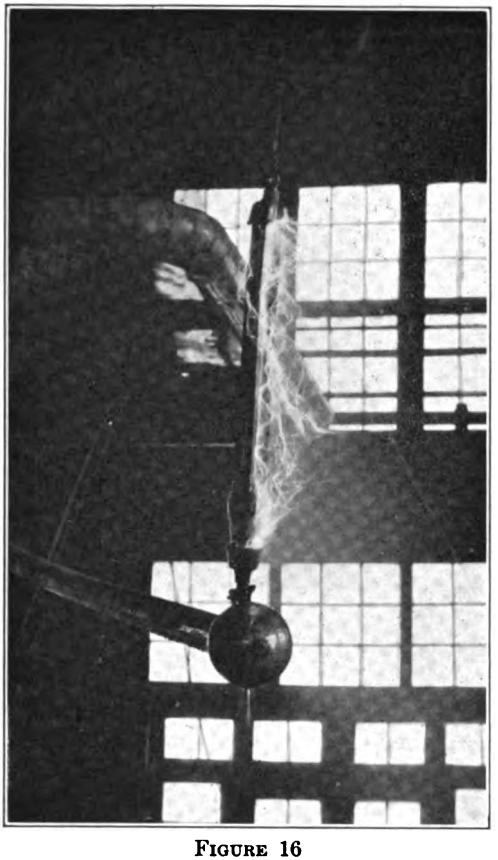

FIGURE 16

face of the rod—until breakdown occurs. This is clearly shown in the photograph.

The tubular insulator previously shown in Figure 3 does not contain the wooden rod, but has been furnished with a pitch filling. In testing, at radio frequency, samples of these insulators, a number of them exhibited characteristics of high grade insulators; others failed by leakage on the inside of the tube at relatively low voltage. These failures must have been due to entrapped moisture or impurities in the pitch.

Tubular insulators of porcelain are manufactured by wet process methods. Smaller insulators for outdoor radio service, manufactured by dry process methods, have proved unsatisfactory because of the fact that moisture is absorbed.

Tests were made on an insulator made from 1-inch (2.54 cm.) diameter manila rope five feet (152.4 cm.) long, the rope having

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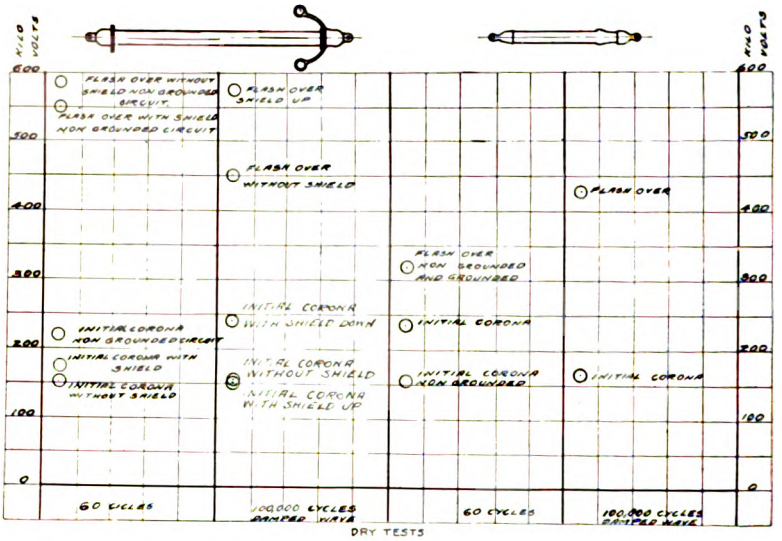

FIGURE 17

been impregnated with linseed oil by a vacuum process. The high voltage end was protected by a bell-shaped shield 20 inches (50.8 cm.) in diameter and 16 inches (40.6 cm.) long. Under dry conditions, the insulator first showed signs of stress at 91

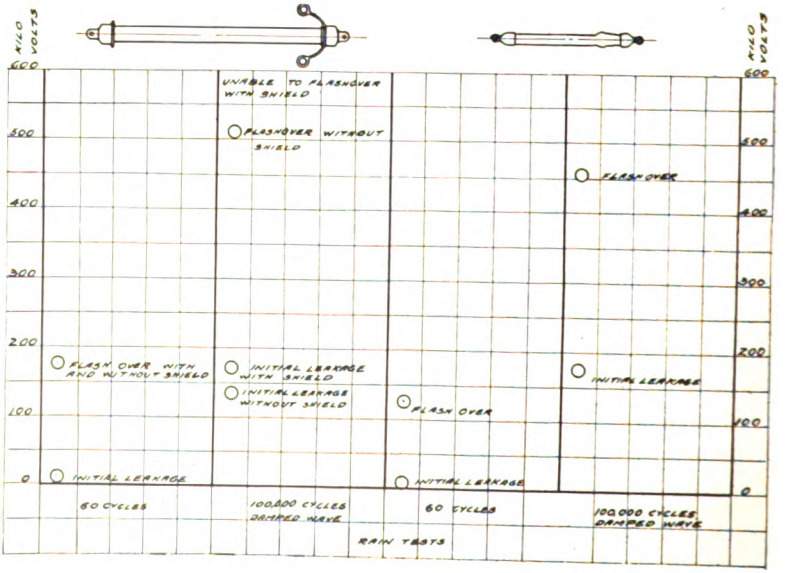

FIGURE 18

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kilovolts at a section 6 inches (15.2 cm.) outside of the shield—22 inches (55.8 cm.) from the high voltage end of the rope. The point of stress was indicated by smoke. Under rain conditions at 30 kilovolts, a temperature rise of 25 degrees above water temperature was obtained, quite evenly distributed along the length of the rope. Immediately after the rain test, a 30 kilovolt

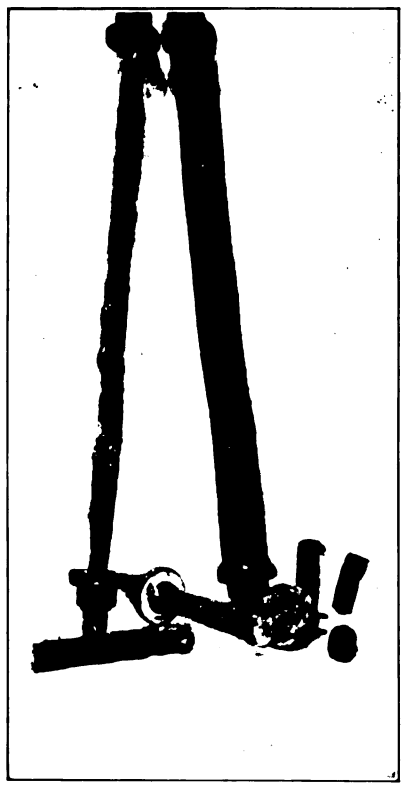

FIGURE 19

run was made for 30 minutes, after which a temperature rise of 40 degrees above air was obtained, quite evenly distributed along the length of the rope. Steam arose from the rope over its entire length and occasional sparking was observed on the surface. Under both the rain and drying conditions, apparently, the point of greatest stress was not 6 inches (15.2 cm.) outside the shield, as under dry conditions, but 8 inches from the grounded end.

Figure 20 shows various types of insulators which have and are being used for antenna insulators.

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Distribution of Voltage Across Insulators in Series

The uneven distribution of voltage across insulators in series is the subject of a number of published articles that treat the subject quite thoroly.[2]

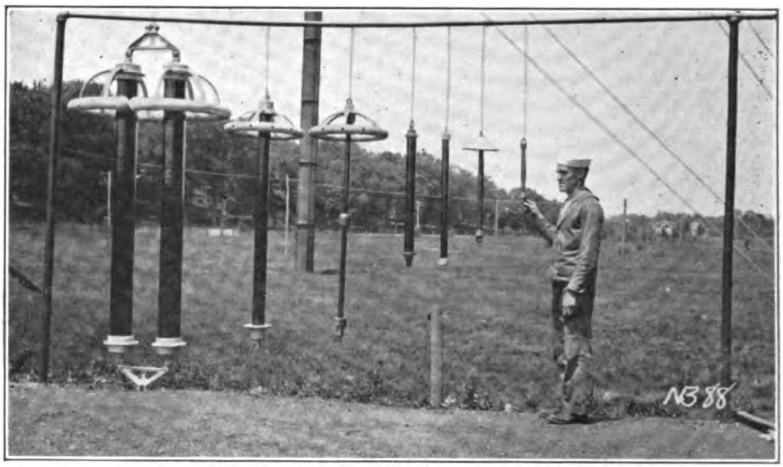

Figure 20

The voltage across any insulator in a series group is directly proportional to the current thru the insulator. The electrostatic capacities between the insulator fittings and the nearby ground and high voltage structures tend to cause uneven current to flow in the various insulators, as shown in Figure 21. In this Figure, condensers C_1, C_2, C_3, C_4, and C_5 represent the electrostatic capacities between fittings of each insulator; condensers C_6, C_7, C_8, and C_9 represent the capacities of fittings to ground, and condensers C_{10}, C_{11}, C_{12}, and C_{13} represent the capacities of fittings to the high voltage structure. Capacities to ground tend to increase the current thru insulators toward the high voltage end of the string, and capacities to the high voltage structure tend to increase the current thru insulators toward the grounded end of the string. The best way to obtain a more even distribution of voltage is to increase the capacities to the high voltage structure, represented by condensers C_{10}, C_{11}, C_{12}, and C_{13} in this Figure.

An example of series insulators in an antenna is in the Marconi

[2] Baum: "Voltage Regulation and Insulation," "Journal of the American Institute of Electrical Engineers," August, 1921.
Peek: "The Insulation of High Voltage Transmission Lines," "General Electric Review," February, 1922.
Chireix: "Distribution of Voltage Along an Insulator Chain," "Radioelectricité," volume 3, number 7, July, 1922.

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type antennas as originally erected at the New Brunswick and Marion stations.

A triatic was suspended between two towers, and a string of 21 compression type insulators in series was used to insulate each end of the triatic from the grounded towers. The antenna conductors were suspended from the triatic by tubular insulators. Considering the triatic insulators as a unit, it has been found by measurement that approximately two-thirds of the total antenna voltage exists across the triatic insulators and one-third across the antenna insulators.

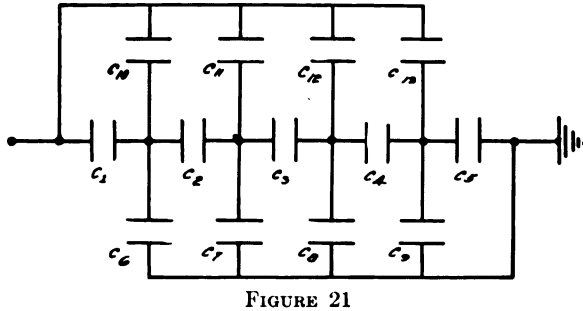

FIGURE 21

The measured distribution of voltage across the triatic insulators is shown in Figure 22 A. An arrangement of shields to re-distribute the voltage across these particular insulators was devised by Mr. J. L. Finch, of the Radio Corporation. The arrangement of shields and the re-distribution of voltage is shown in Figure 22 B.

Tests were made in Schenectady on a string of 20 of these triatic insulators to determine the general characteristics of these strings without and with shields. These characteristics were obtained on a basis of heating of the insulators rather than on voltage distribution. Figures 23 A and B show the results of these tests, which indicate that the effectiveness of the shielding arrangement devised by Mr. Finch increased the flashover and practical operating voltage threefold.

SUPPORTING INSULATORS, BUSHINGS, AND SO ON

Supporting insulators for operation with high voltage radio frequency continuous waves, whether for indoor or outdoor service, should be designed or chosen on the same general basis as insulators for antennas.

The built-up type of supporting insulator in which the sec-

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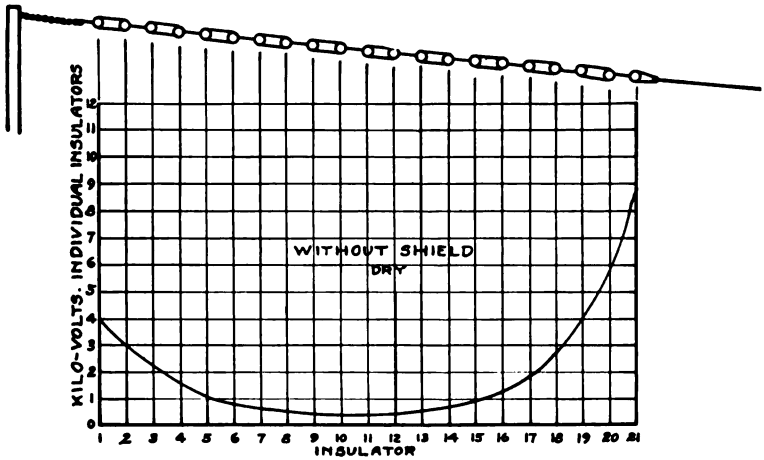

FIG. 22 A

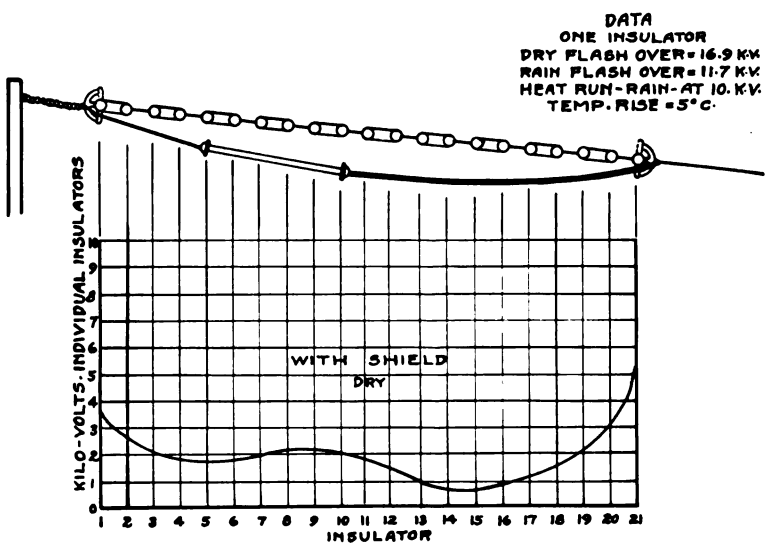

FIG. 22 B

FIGURE 22

tions are fastened together with metal fittings, are not suitable because of their relatively high flux density with the resulting high dielectric losses and the uneven distribution of voltage across the individual sections.

Figure 24 shows in outline an antenna wave change switch which has corrugated porcelain insulators. Spun

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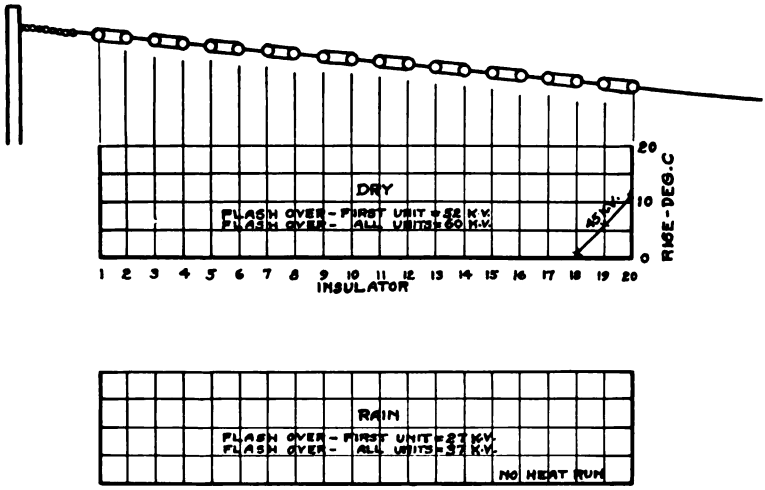
DRY
FLASH OVER - FIRST UNIT = 52 K.V.
FLASH OVER - ALL UNITS = 60 K.V.
20
10
0
RISE - DEG. C
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
INSULATOR
RAIN
FLASH OVER - FIRST UNIT = 21 K.V.
FLASH OVER - ALL UNITS = 37 K.V.
NO HEAT RUN

FIG. 23A

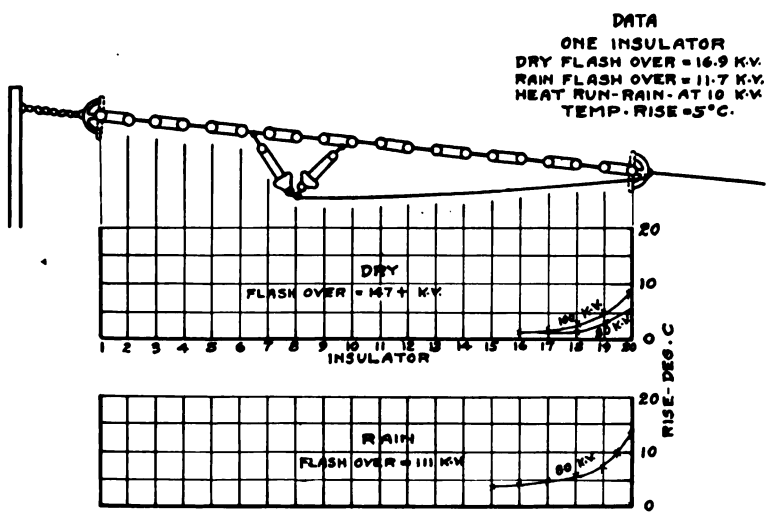
DATA
ONE INSULATOR
DRY FLASH OVER = 16.9 K.V.
RAIN FLASH OVER = 11.7 K.V.
HEAT RUN - RAIN - AT 10 K.V.
TEMP. RISE = 5°C.
DRY
FLASH OVER = 147+ K.V.
20
10
0
RISE - DEG. C
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
INSULATOR
RAIN
FLASH OVER = 111 K.V.
80 K.V.

FIG. 23B

FIGURE 23

aluminum rain-electrostatic shields protect the high voltage ends of the insulators.

Figure 25 shows corona at 113 kilovolts and flashover at 119 kilovolts under dry conditions on the switch shown in Figure 24. Corona, as shown in the top photograph, is due to the small conductor used during these tests and to unprotected edges of fittings. These conditions do not exist in actual installations.

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In Figure 26, the photograph at the top shows corona and leakage at 109 kilovolts on the same switch under rain conditions. The photograph at the bottom, in Figure 26, shows repeated flashover at 116 kilovolts under rain conditions. For all of these tests, the switch arm was closed in one position and grounded and the voltage applied to the open contact clip.

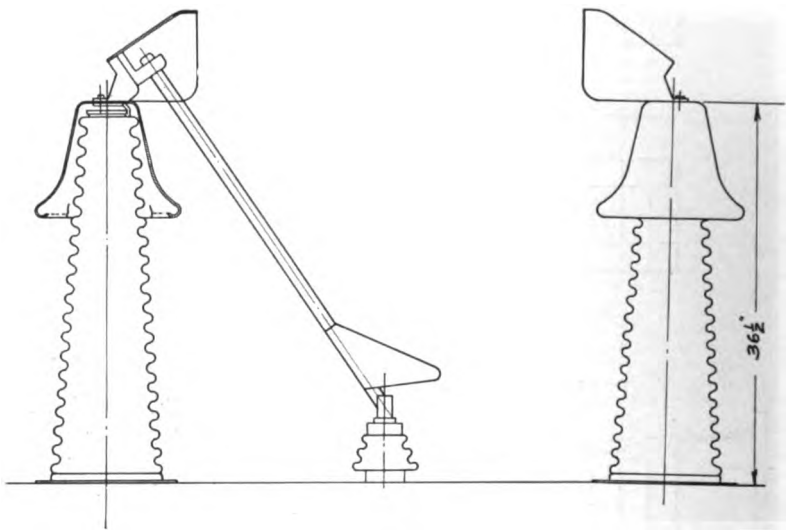

FIGURE 24

Figure 27 shows in outline several types of supporting insulators and bushings suitable for the requirements of radio circuits.

VISUAL CORONA POINT AT 27,000 CYCLES ON CONDUCTORS

Incidental to the insulator tests made at Schenectady, an investigation was made on conductors of various sizes to determine the critical visual corona point. A sample conductor 30 feet (9.15 m.) long under test was suspended horizontally at an average height of 15 feet above ground. A large semi-circular metal plate—grounded—was placed near the center of the 30 foot (9.15 m.) span of wire to simulate a mast of the New Brunswick type. The usual corona point was determined on each size of conductor at distances from 1 to 8 feet (30.5 cm. to 244 cm.) between the wire and the mast. Figure 28 shows the results of these tests. Under the conditions of the test, it is considered that the mast determined, to a large extent, the corona point for the short distances, but that, for the longer distances, the effect

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of the ground beneath the wire was the determining factor. These factors should be taken into account in applying these data to antenna conditions. The shielding effect between multiple wires in an antenna will tend to increase the corona point.

The tests referred to in this paper were made at the direction of Mr. E F. W. Alexanderson. I wish to take this opportunity to acknowledge with thanks the helpful co-operation of Mr. C. H. Taylor, Mr. J. L. Finch, and Mr. C. W. Hansell, of the Radio

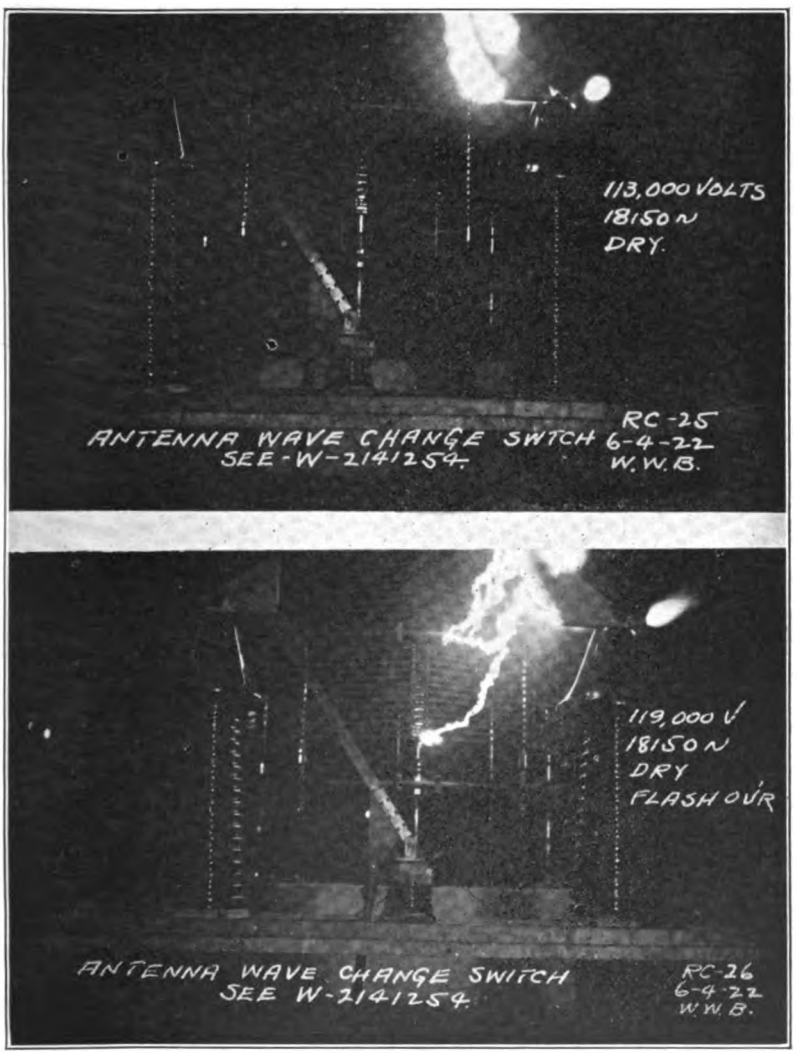

FIGURE 25

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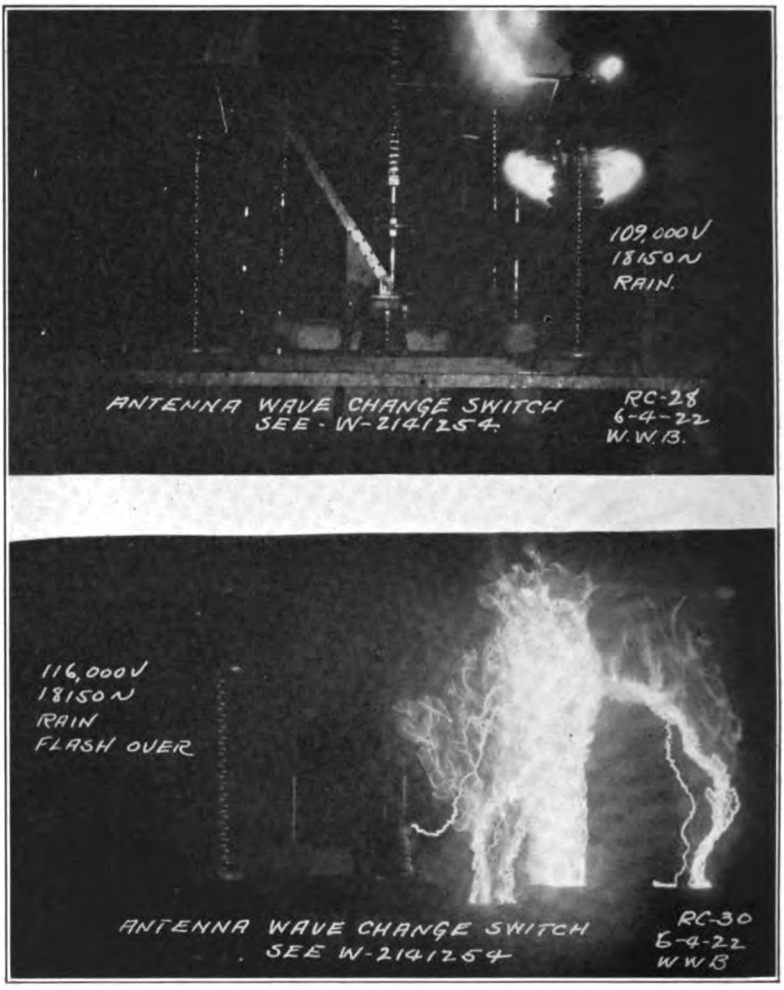

FIGURE 26

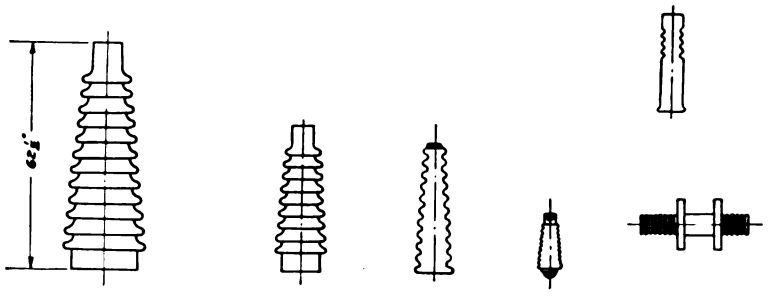

FIGURE 27

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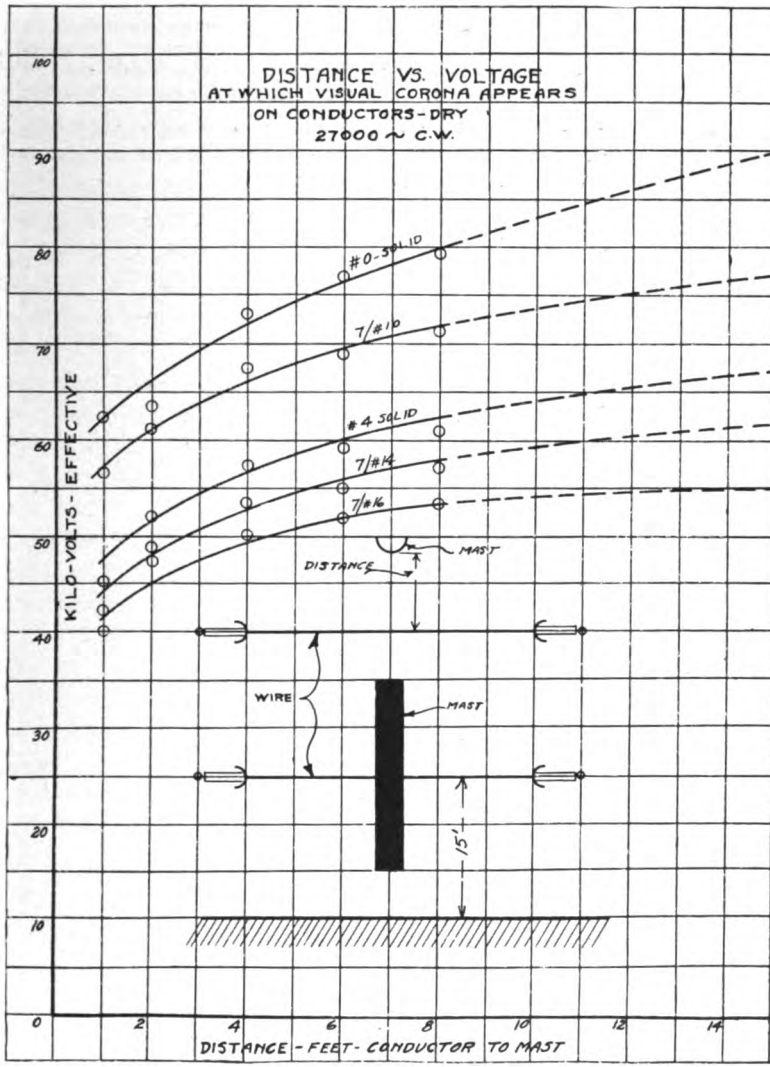

FIGURE 28

Corporation of America; Mr. A. K. Hawley and Mr. A. G. Benard, of the Locke Insulator Company, and Mr. S. P. Nixdorff, of the General Electric Company.

General Electric Company,
Schenectady, New York.

February 12, 1923.

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SUMMARY: After analyzing the design considerations for high voltage radio frequency continuous wave antenna insulators, there are given data on the heating, losses, and flashover points of a number of sizes and forms of porcelain rod insulators, both dry and wet. The effect of rain shields, electrostatic strain shields, and "breathers" on the behavior of the insulators is discussed.

The voltage distribution across insulators in series was determined. Its effects on design are given. A study of visual corona point on conductors at radio frequencies is included.

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DISCUSSION

D. C. Prince (by letter):* The author of this paper has stated that dielectric flux density, which is merely another way of saying potential gradient, decreases with increasing distance between electrodes. He does not attempt to formulate the law of that variation, because the law is much too complicated to be covered in brief and would represent a digression from his subject.

It is often useful to form a general idea of what is accomplished when electrodes are moved apart, in reducing capacity, dielectric flux density and potential gradient, all of which are closely related. The capacity of two concentric cylinders, one of which has twice the diameter of the other, is about 80.8 microfarads per meter of length. To find the capacity between a large cylinder and a small wire along its axis, it is only necessary to find how many times the wire size must be doubled to obtain the cylinder diameter. Each time the diameter is doubled is equivalent to a condenser of 80.8 mmf. capacity per meter in series, so that the final capacity is 80.8 in micro-microfarads per meter length divided by the number of doublings.

If a potential difference is established between wire and cylinder, the different 80 mmf. condensers divide the voltage equally. Thus, if the wire diameter is one-quarter inch (0.64 cm.) and is doubled ten times to give a cylinder diameter of 10 feet 8 inches (2.7 m.), a voltage of 1,000 will give 100 volts drop in the first one-eighth inch (0.32 cm.) from the conductor and 100 volts in the last 2 feet 8 inches (0.68 m.) from the cylinder. This gives a ready measure of the concentration of potential gradient and dielectric flux around a wire lying along the axis of a cylinder.

The capacity of a wire to a plate with which it is parallel is the same as that of the same wire to a concentric cylinder having a diameter four times the distance from wire to plate. This assumes the distance between wire and plate to be several diameters, so that the equipotential surfaces immediately around the wire are nearly concentric cylinders. If the capacity of wire to cylinder and wire to plate are the same and the same voltage is impressed, the same gradient around the wire will result.

If a single long insulator or a string of insulators is stretched from a wire, it obviously varies the potential distribution somewhat. However, a consideration of the potential gradients in air is the first step to a realization of the phenomena underlying the concentrations of voltage gradient and dielectric flux density which produce the results discussed in Mr. Brown's paper.

*Received by the Editor, March 4, 1923.

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A. O. Austin (by letter):* In looking over the paper it would appear that the insulators placed on test are practically all of the porcelain rod type. This type of insulator has been used to a very large extent owing to war conditions. The mechanical hazard of this type of insulator will cause it to be eliminated, simply as a matter of time.

Most systems can operate with a cap and pin type of suspension insulator when the same is modified slightly.

For the very large high grade stations it is advisable to insulate the tower by inserting insulators at several different zones, particularly near the top. By using a method of this kind, the effective height of the tower is increased and a high degree of reliability is maintained. The absence of a large number of insulators in multiple also cuts down leakage losses, which is a decided advantage.

Insulators of the insulated control type are far more reliable and can be operated at a much higher voltage than any of the insulators with the bare screen. The problem involved in insulating the super-power lines of the future are the same as those in connection with radio work in many respects.

W. W. Brown (by letter): In comparing the problems involved in insulating high power radio antennas and super-power lines of the future, we must not lose sight of the fact that flux densities which are permissible in insulators for 60 cycles can seldom be used in insulators subjected to radio frequency continuous waves, because of the high dielectric loss. It is because of the fact that a tubular or rod insulator may be effectively shielded in a simple manner and obtain satisfactorily low flux densities in the dielectric that this type of insulator gives satisfactory service at radio frequencies.

Statistics show that, mechanically, the tubular type of insulators is entirely satisfactory, as mechanical failures are extremely rare under all conditions in which the electrical ratings are not exceeded.

The effective height of a given antenna is undoubtedly higher with the insulated towers than with grounded towers. When it is considered that so-called insulated tower is electrostatically coupled to antenna and ground, the apparent advantage of insulating the tower is not fully realized. It is our opinion that the difficulties encountered in insulating the large tower structures and the expense involved are not justified by the advan-

*Received by the Editor, March 4, 1923.

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tages which might be realized. The trend, in the design of large antennas, appears to be away from insulated towers. An example of this is the 860-foot (262-meter) tower at the Tuckerton Station which was originally erected with insulators, but these have since been removed.

April 18, 1923.

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VACUUM TUBES AS POWER OSCILLATORS*

(PART III)

BY

D. C. PRINCE

(RESEARCH LABORATORY, GENERAL ELECTRIC COMPANY, SCHENECTADY, N. Y.)

CHAPTER VI

POWER AMPLIFIER CIRCUIT

Because of its constant frequency characteristics, there are some applications for which it is desirable to secure a higher power radiation by establishing a lower power oscillation under very constant conditions and then amplifying these oscillations by means of a higher power vacuum tube. The problems encountered by doing this are most pronounced when the load circuit is very highly tuned. It is therefore instructive to examine the operation of a power amplifier for conditions such as those presented by a large trans-Atlantic antenna.

Figure 42 has been drawn up showing the effects on the primary circuit given at various frequencies and with various degrees of coupling. We are informed that changes in wind and temperature may change the antenna capacity sufficiently to change its resonant frequency 0.3 percent.

First assume that an amplifier battery is conductively coupled to the antenna as shown in Figure 44. For simplicity, we will select a coupling of 20 ohms, since this is the largest scale coupling curve completely shown on Figure 42. The following table shows the total impedance presented to the tube output current from the curve at various amounts of detuning.

Detuning %	0	0.05	0.10	0.15	0.20	0.25	0.30
Resistance	22.2	20	16	11.5	8.4	6.2	4.7
Reactance	0	6.4	10.3	11.2	11.0	10.1	9.2
Impedance	22.2	21.0	19.0	10.1	13.8	11.95	11.32

*Received by the Editor, March 15, 1923. Continued from PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS, volume 11, numbers 3 and 4, June and August, 1923.

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It is apparent that maximum impedance occurs at resonance. Since with constant emission and grid excitation the current cannot rise with decreasing impedance, we may assume it constant. Output is then the square of current times resistance. Input remains constant.

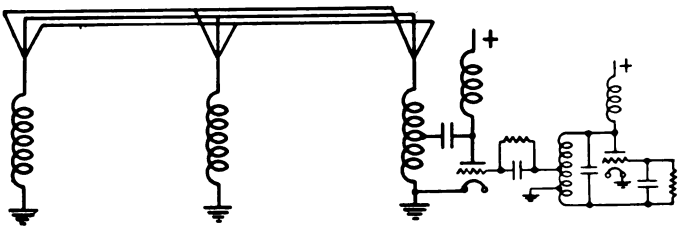

FIGURE 44—Power Amplifier Circuit Directly Connected to Antenna

$$200 \text{ kw. at } 22.2 \text{ ohms} = \sqrt{\frac{200{,}000}{22.2}} = 95 \text{ amperes.}$$

If the efficiency at resonance is 80 percent, input is 200 0.8 = 250 kw. The corresponding outputs and losses are shown in the following Table. Antenna current is proportional to the square root of power output and is also given.

Detuning %	0	0.05	0.10	0.15	0.20	0.25	0.30
Resistance (effective)	22.2	20	16	11.5	8.4	6.2	4.7
Output Kw	200	180	144	103.5	75.7	55.8	42.3
Loss Kw	50	70	106	146.5	174.3	194.2	207.7
Antenna Current %	100	95	85	72	61.5	53	46

It is apparent that detuning 0.1 percent doubles the loss and reduces the current to 85 percent of its maximum value. A further detuning to 0.3 percent again doubles the tube loss and reduces the radiation to less than 50 percent. At the wave length being used 0.1 percent represents 18.3 cycles and 0.3 percent represents 54.9 cycles. It is doubtful if these frequency variations would justify the adoption of this system in this case. The variations in tube loss and antenna current are undoubtedly more important than the slight frequency variations.

By interposing an intermediate circuit between antenna and tubes, the situation is altered somewhat. The circuit is shown in Figure 45. The impedance characteristics can still be taken from Figure 42.

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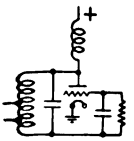

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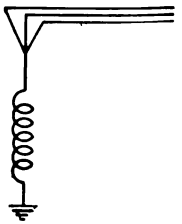

FIGURE 44—Pov

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250 kw. The c
following Table
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Detuning %	
Resistance (ef ive)	
Output Kw.	
Loss Kw.	
Antenna Cu %	

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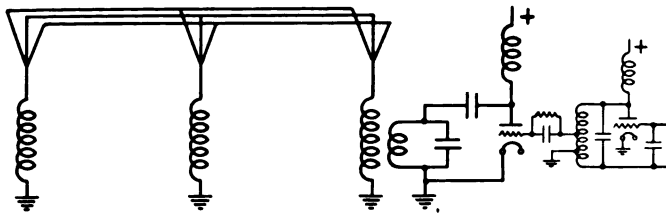

FIGURE 45—Power Amplifier Circuit Connected to Antenna Thru an Intermediate Circuit

The full line curves represent apparent primary reactance due to the coupled antenna, while the dotted curves represent apparent primary resistance due to the coupled antenna.

When the antenna is exactly in tune, the reactive component of reaction upon the primary is zero. The resistance component for 200 kw. in the antenna is 4.25 ohms and the required coupling is, by interpolation, about 8 ohms. The power amplifier impresses a voltage upon the circuit sufficient to cause a current of 217 amperes to flow in primary condenser and inductance. Then,

$$E_p = 217 \times 51 = 11{,}070.$$

Kva. in condenser are $217^2 \times 51 = 2{,}400$ wattless leading.

Kva. in inductance are $217^2 \times 51 = 2{,}400$ wattless lagging.

Actual power is $217^2 \times 4.25 = 200$ kw.

Total input = 200 kw.

$$\text{Input impedance} = \frac{11{,}070^2}{200{,}000} = 612 \text{ ohms resistance.}$$

Obviously this result in ohms is not dependent upon the choice of 11,070 volts, but would have been the same with any other voltage.

Now, inspection of the curves on Figure 42 shows that the maximum reactive effect of the antenna occurs for a detuning of only 0.15 percent in frequency. Since this is within the observed variation of the antenna, this point will be passed thru for the variation of 0.3 percent and more often for lesser variations.

For this amount of detuning, but with the same coupling as before, the antenna reacts upon the primary by 2 ohms resistance and 2 ohms inductance as interpolated from the chart. This amount must be added algebraically to the impedance of the inductive leg of the primary. The current in this leg is then

$$\frac{51}{53} \times 217 = 208.8.$$

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Kva. in condenser are $\overline{217}^2 \times 51 = 2{,}400$ wattless leading.

Kva. in inductance are $208.8^2 \times 53 = 2{,}310$ wattless lagging.

Actual power is $208.8^2 \times 2 = 87.2$ kw.

Total 90 Kva. leading, 87.2 kw. energy.

125.2 kva. total

$$\text{Impedance is } \frac{11{,}070^2}{125{,}200} = 978 \text{ ohms}$$

704 ohms reactance

682 ohms resistance

These values are also independent of the choice of 11,070 volts impressed.

Now the vacuum tubes which would supply 200 kw. to this antenna would have an efficiency of about 80 percent and space charge drop of about 10 percent. For purposes of calculation, we may assume that the method of Chapter II is sufficiently accurate, therefore from Figure 14 the angle during which current flows is 125°.

The fundamental component of output current is $\frac{11{,}070}{612} = 18.1$ amperes. The current wave is found as follows: Since the space charge drop is 10 percent, the impressed direct potential is

$$11{,}070 \times 1.41 \times \frac{100}{90} = 17{,}320 \text{ volts}$$

The average current is

$$\frac{200{,}000 \times \frac{100}{80}}{17{,}320} = 14.45 \text{ amperes,}$$

but, since all the current flows in 125°, the average while flowing is

$$14.45 \times \frac{360}{125} = 41.6 \text{ amperes.}$$

$$\cos 62.5° = 0.463.$$

The average between $-62.5°$ and $+62.5°$ (referred to the line of symmetry) =

$$\frac{1}{125°} \int_{-62.5°}^{+62.5°} \cos\theta \, d\theta = \frac{180°}{\pi \times 125°} \times 2 \sin 62.5° = 0.814$$

To this scale the maximum ordinate is 1.

The average positive value of the curve is $0.814 - 0.463 = 0.351$. This same curve, converted to a scale at which the average for 125° is 41.6 amperes, is the positive part of the curve.

$$i = \frac{41.6}{0.351} \cos\theta - \frac{41.6}{0.351} 0.463$$

$$= 118.5 \cos\theta - 54.9$$

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A Fourier analysis of this wave gives, as the r.m.s. value of the fundamental component, 18.1 amperes, as would be expected.

Now, when the antenna is detuned, the current cannot increase, due to the fact that both emission and grid excitation have remained constant. It may decrease, however, especially since the circuit impedance has been increased by detuning. If we should arbitrarily limit the current to a low value, the alternating plate voltage would be low and the current would be limited in no way by the voltage. As the current is gradually raised, a point is approached where the plate voltage becomes zero for a moment. As this point is approached, the angle during which current can possibly flow is rapidly cut down. Referring to Figure 46, which shows the plate current and plate voltage waves, while $C<E$ there is no limit to the time during which current can flow, but when $C=E$ then 2γ is the greatest angle unless the current wave is decidedly deformed. If emission and grid excitation are such that, with the reduced angle, the voltage cannot be maintained, giving $C \geq E$, the value of C cannot rise further. If, on the other hand, C can be maintained even with $\alpha<\gamma$, the current can continue to rise until $\alpha+\beta=\gamma$. At this point the current wave for a given grid excitation can rise no farther for the shape of the current curve is dependant upon grid excitation and no current can flow with the plate negative. In order to find out whether C can be greater than E, it is only necessary to solve the border line case where $C=E$.

Referring to Figure 46, it may be assumed that, for our purpose, the current which does flow is part of the same sine wave of 118.5 amperes amplitude, but that the other or bias term changes.

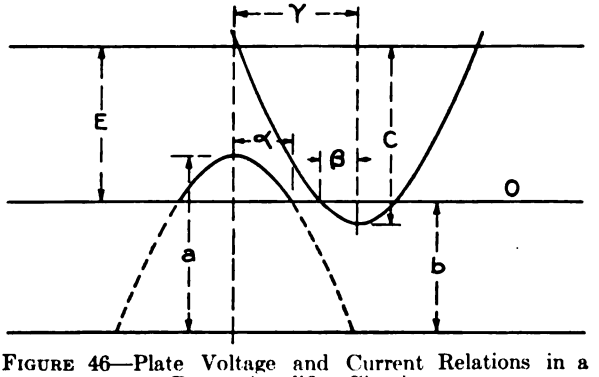

FIGURE 46—Plate Voltage and Current Relations in a Power Amplifier Circuit

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Let E = direct voltage impressed = 17,320 volts.

a = amplitude of current wave = 118.5 amperes.

b = bias of current wave = 54.9 amperes minimum.

C = amplitude of voltage wave.

γ = power factor angle of circuit = $cos^{-1}0.697 = 46°$.

$$\beta = cos^{-1}\frac{E}{C}$$

$$\alpha = cos^{-1}\frac{b}{a}$$

Z = circuit impedance.

R = apparent resistance.

m = amplitude of fundamental component of plate current.

$$\text{Circuit absorption} = \frac{C^2}{2Z^2}R = \frac{C^2 \times 682}{2 \times 978^2} = 356 \times 10^{-6} C^2$$

$$\text{Tube output} = \frac{m C \cos\gamma}{2}$$

For a steady state, the output and absorption are equal, therefore:

$$356 \times 10^{-6} C^2 = \frac{m C \cos\gamma}{2}$$

$$C = \frac{m \cos\gamma}{712 \times 10^{-6}}$$

By Fourier's method:

$$m = \frac{1}{\pi}\int_{\alpha}^{+\alpha} (a\cos^2\theta - b\cos\theta)\, d\theta$$

$$= \frac{1}{\pi}\left[a\left(\frac{\theta}{2} + \frac{1}{4}\sin 2\theta\right) - b\sin\theta\right]_{-\alpha}^{+\alpha}$$

$$= \frac{1}{\pi}\left(a\alpha + \frac{a}{2}\sin 2\alpha - 2b\sin\alpha\right)$$

If $C > E$, $\alpha < \gamma$. In the dividing case $C = E$ and $\alpha = \gamma$.

Then $b = a\cos\gamma = 118.5 \times 0.697 = 82.6$, and

$$m = \frac{1}{\pi}\left(118.5 \times \frac{46\pi}{180} + \frac{118.5}{2}\sin 92° - 2 \times 82.6 \sin 46°\right)$$

$$= 12.5$$

$$C = \frac{12.5 \times 0.697}{2 \times 356 \times 10^{-6}} = 12{,}240 \text{ volts}$$

It appears therefore that, altho with an unrestricted current angle the voltage could have risen so that $C = 1.41 \times 18.1 \times 978 =$ 25,000 volts, the restriction in current angle prevents a higher

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value than 17,320, which is E. Actually, it is restricted to a slightly lower value, because considerable current must flow at the point in the cycle when the alternating plate voltage is at its maximum value. If we assume that a difference between plate and filament potentials of 1,000 volts will be sufficient, then for $C = 16{,}320$

$$m = \frac{16{,}320 \times 2 \times 356 \times 10^{-6}}{0.697} = 16.7$$

To determine the current curve, assume a series of values of α. The computation is shown in the Appendix to this Chapter (Table III), from which, by interpolation, for $m = 16.7$, $\alpha = 53°$

Output $= C^2 \times 356 \times 10^{-6} = 16{,}320^2 \times 356 \times 10^{-6} = 94.8$ kw.

Input $= E \times i$ average

$$= 17{,}320 \times \frac{1}{\pi} \int_0^{53°} (118.5 \cos\theta - 71.3) d\theta$$

$$= \frac{17{,}320}{\pi} \left(118.5 \sin 53° - 71.3 \times \frac{53}{180} \pi \right) = 158.8 \text{ kw.}$$

Loss = 64 kw.

Thus, by using an intermediate circuit, the loss has been prevented from rising as rapidly as when no intermediate circuit was used. A further detuning causes a further rise in impedance with probably lessened loss.

The method here used is too approximate for great reliance to be placed upon it, altho it shows the order of performance, which may be expected with a power amplifier circuit using a grid resistance bias. An exact study can, of course, be made by the method developed in Chapter I. Due to the inconstancy of grid phase angle, many special phenomena are bound to occur under detuned operation. Upon their seriousness, in any given case, will depend the care which must be exercised in maintenance of adjustment.

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Appendix to Chapter VI

Table III

Analysis of Current Wave to Find Unity P. F. Component

Let a =	45°	50°	55°	60°
a (radians)	0.787	0.875	0.960	1.050
$\sin a$	0.707	0.768	0.820	0.867
$\sin 2a$	1.00	0.98	0.94	0.867
$\cos a$	0.707	0.643	0.573	0.500
$b = 118.5 \cos a$	0.837	76.2	68.0	59.3
$\frac{a\,a}{\pi}$	29.7	33.0	36.2	39.6
$\frac{a}{2\pi} \sin 2a$	18.9	18.5	17.75	16.35
$\frac{2b}{\pi} \sin a$	37.7	37.3	35.5	32.8
m	10.9	14.2	18.45	23.15

Chapter VII

Improvement of Oscillator Efficiency by the Use of Harmonics

In all of the foregoing analyses, it was assumed that the circuits were so tuned as to respond sinusoidally. Thus the doubly periodic circuits have been adjusted to avoid having one frequency a multiple of another, and so on. As long as the circuit response is sinusoidal, the fundamental current component in phase with the voltage alone represents output and all other components are loss. The following discussion shows that efficiency and output conditions may be changed materially if arrangements are made to have the load circuit responsive to certain harmonics, so that all input on these harmonics need not be absorbed as tube loss.

Referring to Figure 47, let:

X = impressed direct potential.

e_p = instantaneous drop from plate to filament.

e_g = instantaneous drop from grid to filament.

i_p = instantaneous plate current.

i_g = instantaneous grid current.

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Then

$X\, i_p$ = instantaneous input.

$(X - e_p)\, i_p$ = instantaneous output neglecting grid loss.

$e_g\, i_g$ = instantaneous grid loss.

$(X - e_p)\, i_p - e_g\, i_g$ = instantaneous net output.

$\dfrac{(X - e_p)\, i_p - e_g\, i_g}{X\, i_p}$ = instantaneous efficiency.

θ_1 = Angle at which $i_p = 0$.

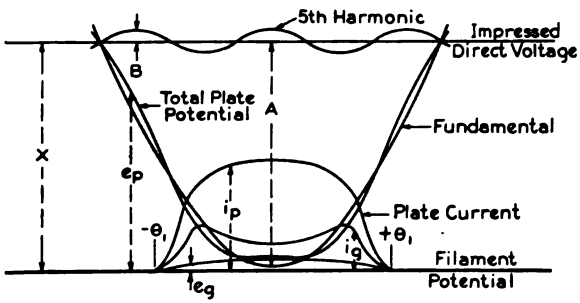

FIGURE 47—Plate Potential and Current Waves for Circuit Containing an Harmonic Trap

Neglecting for the moment the grid loss, $\dfrac{(X - e_p)}{X}$ = instantaneous efficiency. For high average efficiency, it is only necessary to keep e_p small for a considerable portion of the cycle.

This can be done by utilizing a voltage wave which is not a pure sine wave, but contains harmonics in the proper phase relations to give a flat topped wave as shown in Figure 47. It is obviously not sufficient to show that such a harmonic, if it existed, would improve efficiency. The harmonic must be set up in a circuit tuned to it, and the losses of that circuit must be supplied by the oscillator. Otherwise, the whole matter is of hypothetical interest only. We will, therefore, assume a desired harmonic to exist in the voltage wave and examine whether there will be sufficient output on that harmonic to maintain the harmonic voltage.

Let,

$e_p = X - A \cos\theta + B \cos n\theta$

Then

$(A \cos\theta - B \cos n\theta)\, i_p$ = output neglecting grid losses, that is:

$A \cos\theta \cdot i_p$ = output on the fundamental

$-B \cos n\theta \cdot i_p$ = output on the nth harmonic.

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If, when i_p is determined by means of a tube characteristic, the harmonic in question is shown to have a sufficient positive output, it may be built up in a resonant trap circuit as shown in Figure 49, to maintain the voltage wave in its proper amplitude and phase. If the harmonic output is very small, it may not be sufficient to sustain the voltage. If it is negative, a harmonic voltage in the wrong phase will be built up. This will give a peaked rather than a flat topped voltage wave and reduce the efficiency rather than increase it.

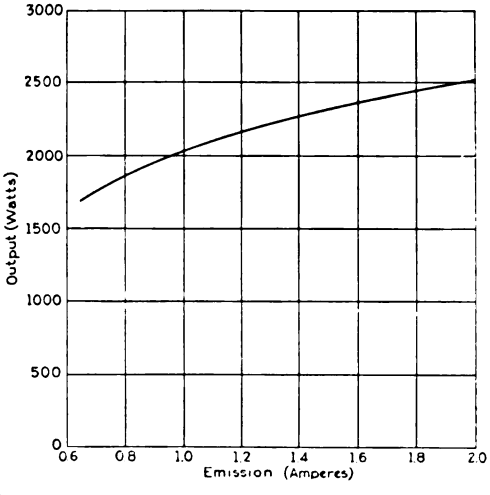

FIGURE 48—Calculated Variation of Output of a UV-206 Radiotron with Emission at 15,000 v. d. c. and 350 Watts Tube Loss

The cases of positive and negative harmonic outputs can readily be demonstrated by calculating for the same current wave the harmonic output on two different harmonics. The assumed characteristic is shown on Figure 4. For sinusoidal plate and grid excitation, the outputs, losses and efficiencies are shown in Table IV. Obviously from Figure 47 the instantaneous harmonic outputs for $\theta_1 = 0$ are negative for a flat topped wave. In order for the net output to be positive, therefore, three half cycles of the harmonic must occur while current is passing. That is, if a fifth harmonic is to be built up, the opening angle should be approximately 108° and, if a third harmonic is desired, approximately 180°. The corresponding values of θ_1 are 54° and 90°, respectively or, for round numbers, 60° and 90°, θ_1 being half the opening angle.

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Table V shows the calculated performance using a fifth harmonic in the voltage wave. It is apparent that at $\theta_1 = 60°$ sixteen watts are available to sustain the harmonic oscillation, while for $\theta_1 = 90°$ no energy is available. Table VI shows the corresponding calculated performance using a third harmonic in the plate potential. For $\theta_1 = 60°$ the harmonic output is -77 watts, so that the harmonic would tend to build up in the wrong phase and no good results would follow. For $\theta_1 = 90°$ thirty-eight watts are available for losses in the harmonic trap circuit. The relation between available harmonic watts and harmonic voltage is determined by the trap circuit design.

Thus with the characteristic and circuit constants shown, it is possible, with an efficient harmonic trap, to improve over-all efficiencies materially. The output of a properly designed tube is limited by the permissible heat dissipation. The variation of output with efficiency is, therefore, expressed by the relation,

$$\frac{\text{Output}}{\text{Losses}} = \frac{\text{Efficiency}}{1-\text{Efficiency}}$$

On this basis, when θ_1 is 60°, the output is increased 57 percent by the use of a fifth harmonic circuit, and when θ_1 is 90°, an increase of 95 percent is obtained by the use of a third harmonic circuit.

Such an increase as that noted assumes that efficiency is solely a function of opening angle which is not necessarily the case. Table VII shows the effect of varying emission on efficiency and output for $\theta_1 = 60°$. From this it appears that by maintaining the opening angle and increasing the emission, the efficiency is only slightly affected, so that without harmonic circuits a higher emission merely overheats the tube.

Some additional output can be obtained by increasing emission and reducing opening angle without harmonic circuits. The increase of 57 percent in output at $\theta_1 = 60°$ by using a fifth harmonic corresponds to an emission increase of approximately 51 percent, that is, from 0.7 to 1.1 amperes. Figure 48 shows the increase of output obtainable by increasing emission and reducing opening angle to maintain constant loss. The increase of emission from 0.7 to 1.1 would increase output 20 percent without the use of an harmonic circuit. The increase possible by the use of the harmonic circuit must rightly be referred to this figure. The net improvement ascribable to the harmonic is therefore $\frac{157-120}{120}$, or 30 percent. That no such

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gain is obtainable by further increase in emission, without harmonics, is apparent from the curve.

Where the harmonic output is insufficient to maintain the oscillations in the harmonic circuit, it is necessary to reinforce it. Anything which will flatten the current wave will add to the harmonic output. Emission limitation tends in this direction or a small part of the harmonic energy may be returned to the grid and the harmonic built up to any desired value. The fraction of the total harmonic energy supplied in this latter way must be relatively small as otherwise there is nothing to maintain the proper phase relations.

Figure 49 shows the type of circuit in which a plate potential harmonic can build up.

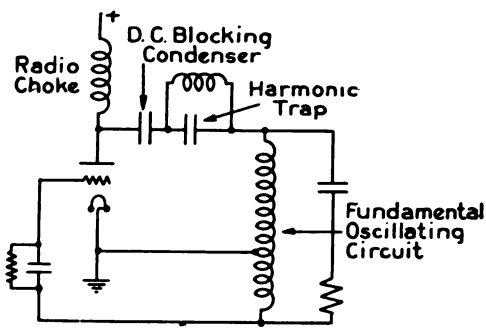

FIGURE 49 Harmonic Trap Oscillating Circuit

The foregoing conclusions are based on calculations from characteristic curves and not upon input and loss tests of an oscillating tube. To this extent they are theoretical. The principles involved in the calculations are all simple and have been verified by tests on sine wave circuits. Since the characteristics of different types of tubes are apt to vary, particularly with regard to the harmonic content of the current wave, the proper method of securing harmonic energy cannot be stated in the general case. The amount of increase in output obtainable depends upon the efficiency of the tube as represented by the percentage of the total voltage necessarily lost in space charge drop. The higher the efficiency in this respect, the greater will be the percentage improvement from the use of the harmonic circuit.

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Table IV

15,000 Volts 0.7 Ampere Emission
Plus 650 Grid Maximum
813 Minimum Plate

θ_1	50°	60°	70°	80°	90°
Input	1,828	2,165	2,500	2,860	3,180
Electron Loss	264	380	523	717	928
Total Loss	316	415	546	730	932
Output	1,512	1,750	1,954	2,130	2,248
Efficiency	82.7	80.9	78.2	74.5	70.7

Table V

15,000 Volts 0.7 Ampere Emission
Maximum Fundamental 15,000
Maximum Fifth 800
Maximum Plus Grid 640

θ_1	50°	60°	70°	80°	90°
Input		2,100			3,150
Electron Loss		224			778
Total Loss		274			782
Fundamental Output		1,826			2,368
Efficiency		87			75
Fifth Harmonic Output. (Counted as Loss)		16			0.1

Table VI

15,000 Volts 0.7 Ampere Emission
Maximum Fundamental 16,400
Maximum Third 2,200
Maximum Plus Grid 640

θ_1	50°	60°	70°	80°	90°
Input		2,130			3,110
Electron Loss		165			496
Total Loss		198			538
Fundamental Output		2,009			2,572
Efficiency		....			82.5
Third Harmonic Output. (Taken as loss where +)		−77			+38

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TABLE VII

15,000 Volts
Minimum Plate 800 Volts
Maximum Plus Grid 640 Volts
$\theta_1 = 60°$

Emission	0.7	1	1.5
Input	2,165	2,820	3,570
Electron Loss	380	468	560
Total Loss	415	505	617
Output	1,750	2,315	2,953
Efficiency	80.9	82	82.5

APPENDIX

RADIOTRON THEORY

A brief review of some of the less obvious features of tube performance may contribute to the solution of certain problems. In the following discussion an attempt is made to cover the various factors briefly, giving the theroretical equations and indicating the degree of correspondence between quantitative theory and practice.

EMISSION

A tungsten filament heated gives off electrons. The volts, amperes, watts, and temperature for a given emission from a ten-mil filament are shown in Figure 50. The values so obtained practically never correspond to those observed in an actual radiotron. The reasons for the departure are of two kinds. Temperature effects are introduced by the other electrodes and by the filament-supporting structure and by the emission currents themselves. The enclosing electrodes tend to reflect a considerable amount of heat back to the filament. In a perfectly symmetrical cylindrical tube reflected heat is focused on the filament so that the rated current may considerably overheat it and increase emission. Voltage has a less effect since the increased temperature is accompanied by increased resistance. The usual unsymmetrical filaments are not so positioned as to receive any great heat reflection.

Leads and supports exert a cooling effect on the ends and other parts of the filament. These effects reduce emission. Such

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a reduction is easily allowed for by considering the effective filament somewhat shorter than the actual length.

If the filament-heating current is alternating, and of a different frequency than the circuit in which the tube is being used, the current in the ends of the filament will be increased symmetrically by the emission current. This effect offsets the cooling due to the leads. If the filament heating is by direct current, or is synchronized with the emission one end of the filament is unduly heated and the total emission is increased considerably.

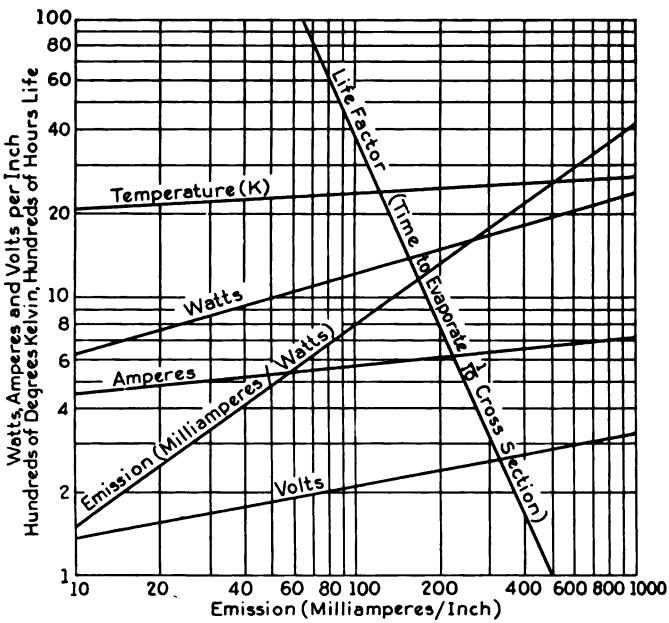

FIGURE 50—Heating Energy for 10 mil (0.01 inch or 0.025 cm.) Filament. For filament of diameter d, holding temperature constant:

$$\text{Emission}_d = \text{Emission}_{10} \times \frac{d}{10} \qquad \text{Watts}_d = \text{Watts}_{10} \times \frac{d}{10}$$

$$\text{Fil. amp.}_d = \text{Fil. amp.}_{10} \times \left(\frac{d}{10}\right)^{\frac{3}{2}} \qquad \text{Life}_d = \text{Life}_{10} \times \frac{d}{10}$$

$$\text{Fil. volts}_d = \text{Fil. volts}_{10} \times \left(\frac{d}{10}\right)^{-\frac{1}{2}}$$

The greatest filament life is obtained when the heating is most uniform over the whole length. This requires either asynchronous heating or heating and emission currents in quadrature.

Besides heating effects, the form of the filament may greatly

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affect emission. A closely wound helical filament e'ectrostatically shields the insides of its turns. A similar tho less marked effect occurs with **V** and **W** filaments. The potential differences between adjacent legs of filaments also interfere with emission from the positive portions.

Altho, theoretically, these shielding effects should appear as changes in space charge rather than in emission, the voltages required to draw off all the electrons emitted become too high for observation in static tests. A typical example of the discrepancy between theoretical (straight filament) and observed emission for a **V** filament is shown in Figure 51. As stated above, a straight filament along the axis of a cylinder will practically equal the theoretical emission or may even be higher, due to heat reflection. It will be noted that the observed emissions in Figure 51 are much closer to the theoretical for large filament current.

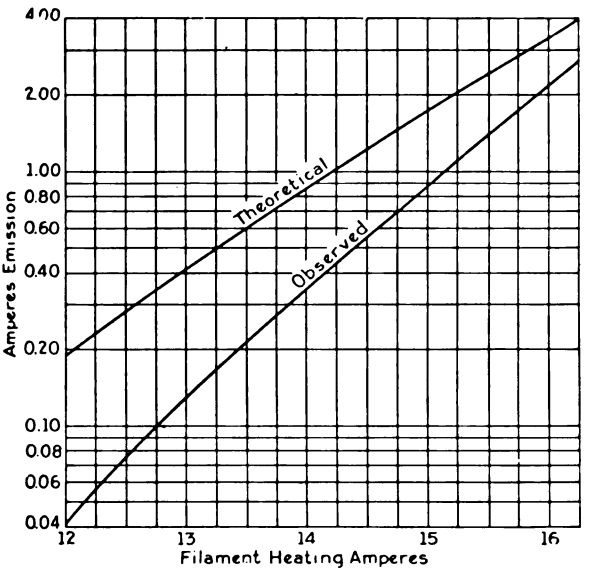

FIGURE 51—Electron Emission for a UV-218 Kenotron. "V" Shaped 18 mil. (0.018 inch or 0.0457 cm.) Tungsten Filament—4.25 inches (10.8 cm.) Active Length

One possible explanation is that, at higher temperatures, the electrons are able to pass by initial velocity out of the regions most shielded by the other strands of filament and supports. The transition from space charge to emission limit is very gradual in tubes having complicated filaments. A good example of this is found in Figure 52. This tube has a double **V** filament

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and support all close together. Theoretical emission is 10 to 12 amperes, but saturation begins to set in at 5 amperes below which point it is presumed that only the outsides of the filament strands are active. Theoretical data is, therefore, not directly applicable in determing emission with present types of filament.

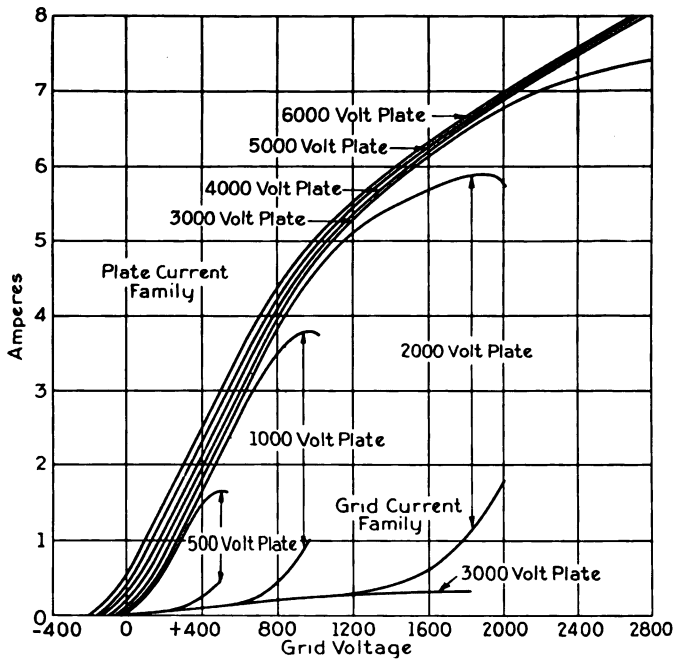

FIGURE 52—Extrapolated Characteristics of a Water-Cooled Radiotron

SPACE CHARGE

The theoretical space charge equation for cylindrical tubes is, $i = 14.65 \times 10^{-6} \frac{LV^{\frac{3}{2}}}{R\beta^2}$. For $\beta^2 = 1$, this relation is plotted in Figure 53. β^2 is a function of relative radii of cathode and anode. When the cathode is more than one-tenth the anode diameter, β^2 is no longer unity. For conditions where β^2 is different from unity, its value is plotted in Figure 54. The above formulas assume that the filament is a constant potential surface. The filament-heating current causes a drop along the filament so that it is not a constant potential surface. The error involved by neglecting this drop is plotted in Figure 55. For an anode potential less than the filament drop, the filament being excited

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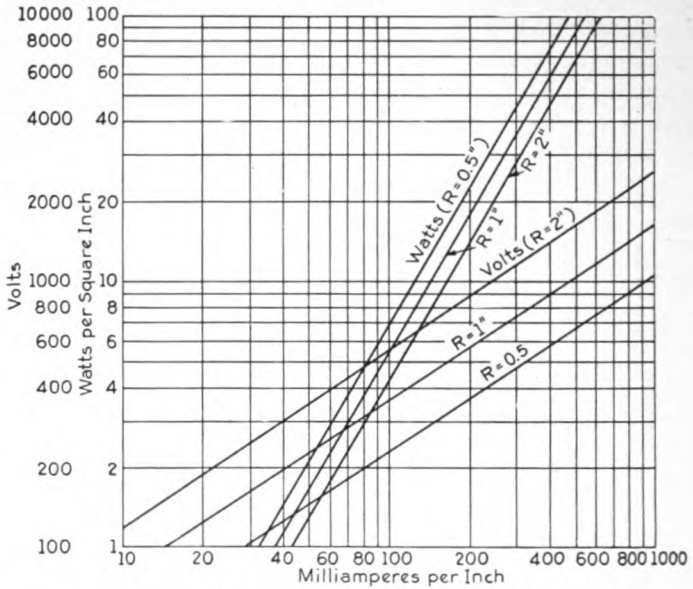

FIGURE 53—Space Charge for Cylindrical Anode of Radius R Computed from Formula $i = 14.65 \times 10^{-6} \frac{LV^{\frac{3}{2}}}{R}$

by direct current, the space charge current is given by the relation

$$i = 0.4 \times K \frac{1}{r^n} \frac{V^{5/2}}{V_o}$$

$K = 14.65 \times 10^{-6}$ for a cylindrical anode

$n = 1$ for a cylindrical anode

V_o = Filament drop.

Some misapprehension exists regarding the closeness of these formulas to practice. In a three-electrode tube, it has been found empirically that the plate voltage-plate current curve for zero grid volts approximates a parabola, and this has been cited by some authors in disproof of the 3/2 power law. In the three-electrode tube, the potential which must be used is the resultant of plate and grid potentials. For amplifier tubes this resultant voltage is practically always of the same order of magnitude as the filament voltage, so that the characteristic varies between the 3/2 and 5/2 power with the square law as a frequent average. This is clearly brought out by van der Bijl ("The Thermionic Vacuum Tube," page 236).

The correspondence between theory and observation is shown by Figure 56. The active length necessary to make theoretical

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and observed curves coincide is 2⅜ inches (6.04 cm.), which, allowing for the cooled ends of the filament, is very close to what would have been expected. The exponent is 3/2. In this case the filament voltage is 11. The departure from the three halves power law is, therefore, only 0.1 percent, according to Figure 55.

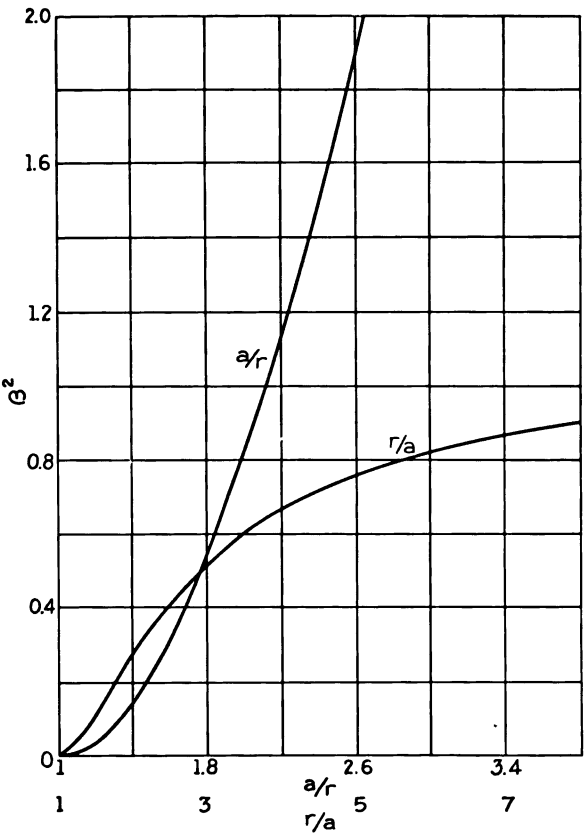

FIGURE 54—Space Charge for Cylindrical Anode and Cathode of Infinite Length. $i = 14.65 \frac{LV^3}{r\beta^2} \times 10^{-6}$, i is current in amp., E is potential in volts, r is radius of anode, a is radius of cathode. L is the length of the section considered. For large values of r/a the value of β^2 approaches unity

In the case of a radiotron, the potential effect inside the grid is a composite of grid and plate voltages. Also the diameter of a cylinder, which would have the same electrostatic effect, is a compromise between grid and plate. For a close mesh grid

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the equivalent diameter is little different from the grid diameter. Figure 57 gives the theoretical space charge current for a tube having the same filament and plate as the kenotron in the preceding paragraph, but with a grid added. Observed values correspond with the theoretical within the limits of experimental error. It appears that below currents at which saturation begins to become apparent, theoretical space charge equations may be used with a high degree of accuracy if the active filament length and effective anode diameter are known.

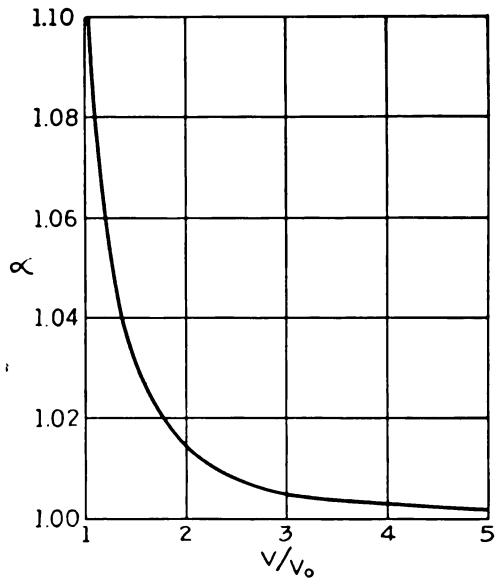

FIGURE 55—Correction for Filament Drop.

$$i = \frac{KL}{r^n}\left(V - \frac{V_o}{2}\right)^{\frac{3}{2}} \times \alpha$$

V is potential between anode and negative end of filament. V_o is filament drop. For $V < V_o$ the active filament length is $L \times \frac{V}{V_o}$ giving

$$i = 0.4\,K\frac{LV^{\frac{3}{2}}}{r^n V_o}$$

AMPLIFICATION CONSTANT

No really successful theoretical equations for amplification constant for radiotrons seem to be available at present. The older formulas usually assume the grid wire diameter very small compared with the spacing. These formulas are greatly in error for very many amplifier and most power oscillator tubes. Even without this limitation, the presence of grid supports is a serious

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source of error. In general, therefore, only empirical methods are available for predetermination of μ.

The determination of amplification constant has, however, been given much study, and a large mass of empirical data is available.

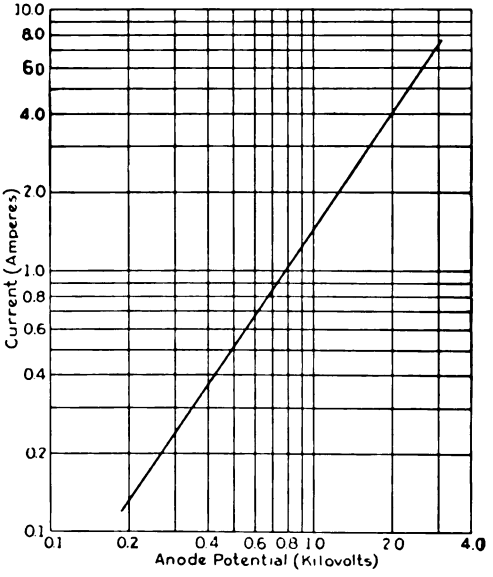

FIGURE 56—Space Charge Characteristic UV-218 Kenotron. "V" Shape 18 mil. (0.018 inch or 0.046 cm.) Filament 5.5 inch (14.0 cm.) long. Plate 1.5 inch (3.8 cm.) diameter by 3 inches (7.6 cm.) long.
NOTE:—This curve obtained by test checks the theoretical values assuming 2.375 inches (6.04 cm.) effective length for each leg of "V"

DIVISION OF PRIMARY ELECTRONS

The most fundamental law applying to the division of current between grid and plate is that the velocity of an electron is proportional to the square root of the potential thru which it has fallen. By the application of this law, an electron cannot strike an electrode negative with respect to the cathode by a potential more than that corresponding to the emission velocity. Therefore, for negative grid potentials, the grid current is zero.

Except near the grid wires themselves, the grid exerts a nearly uniform effect upon the electrons and, as the electrons repel each other, their distribution as they approach the grid is quite uniform. As they approach the grid, they pass into a field radial

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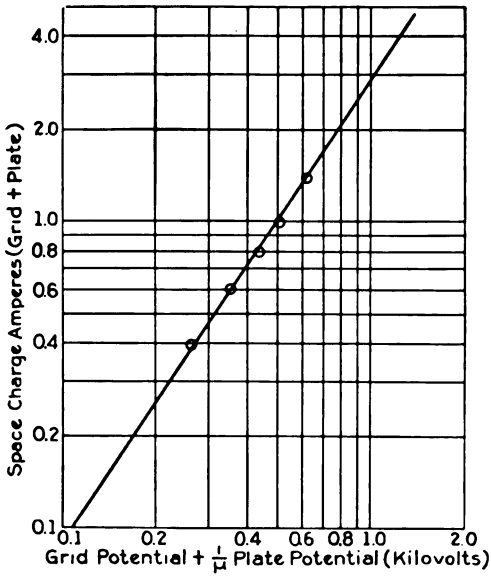

FIGURE 57—Space Charge Current for a UV-206 Radiotron. "V" Shaped 18 mil. (0.018 inch or 0.045 cm.) Filament 5.5 inch (14.0 cm.) long. Plate 1.5 inch (3.8 cm.) diameter by 3 inch (7.6 cm.) long. Grid 30 turns per inch (11.8 turns per cm.) 10 mil. (0.01 inch or 0.025 cm.) wire 0.75 inch (1.9 cm. diameter). $\mu = 250$

NOTE—The curve is the theoretical curve using 2.375 inch (6.04 cm.) active filament length and grid diameter. Experimental points were taken at 16.1 amperes filament.

with respect to the grid wires. Since they have already attained most of their velocity, their inertia will prevent their following this radial field, provided their velocities are in a materially different direction. Those which would strike the grid without deflection will strike it as long as it is positive. A small number of additional electrons will be sufficiently deflected to strike the grid. The number striking will then be a function of projected grid area and, provided the plate is sufficiently positive to collect those which pass thru, the ratio of grid to plate current will be independent of their relative potentials. There is good evidence that the division of primary electrons is determined in this way.

SECONDARY EMISSION

If the conclusion of the preceding paragraph is correct, the departure of the grid-plate current ratio is due to secondary

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emission. Quantitatively, secondary emission is not well understood. Qualitatively, it is known that an electron striking a surface with a velocity of more than about 5 volts may bound off or knock off one or more other electrons. The number is varied by the velocity of bombardment, by the condition of the surface, and by the presence of traces of gas. The velocity of secondary electrons may be a considerable fraction of the bombarding velocity and be of the order of fifty or sixty volts.

Such secondary electrons are normally given off by both grid and plate of a radiotron and greatly affect the current division. For high plate potential and low grid potential, the secondaries travel in greatest numbers from grid to plate so that the grid current may not only be reduced below the projected area value, but may even become negative and cause blocking. As the grid and plate voltages approach one another, the greatest flow turns toward the grid, which may not only receive more current than that determined by the projected area ratio but even more than the plate itself. This accounts for the shape of the characteristics which are included in the body of the report.

The loss of electrons from plate to grid operates to give saturation and to limit the amplitude of oscillations. Its effect is entirely stable, but it operates to limit possible tube output and efficiency. Loss of electrons from grid to plate operates to reduce grid loss and is an advantage up to the point of current reversal. It would still represent an advantage, since the grid then contributes to the output, except that the reversed grid current upsets the usual biasing arrangements.

The geometrical factors that enter into the interchange of secondary electrons are closeness of grid and plate by comparison with plate-filament spacing. When plate and grid are relatively close together, compared with the distance to the filament, there is little space charge between grid and plate, so that there is little opposition to secondary interchange. The reverse is true for large grid to plate spacings.

Much of the material from which the curves in this section were derived was obtained from Dr. Irving Langmuir.

SUMMARY: Chapter VI. In the "master oscillator" or "power amplifier" circuit oscillations are generated by a small power source and then amplified. In the amplifier there is no definite phase relationship between plate and grid potentials. The phase is determined by the tuning of input and output circuits. The effect of variations in grid and plate circuit tuning upon output and losses is developed for both direct coupling to the antenna circuit and coupling thru an intermediate circuit.

Chapter VII—It is shown by the general method of Chapter I that considerable increases in both efficiency and tube output can be obtained by introducing harmonics into the plate voltage wave. The purpose of these har-

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monics is to flatten the top of the wave so that tube losses may be maintained at a minimum value during a large part of the time during which current is flowing.

Appendix—The general explanations of vacuum tube phenomena are supplemented by more detailed data giving the correspondence between theoretical, ideal, and actual values for emission and space charge. The theory of division of primary electrons between grid and plate when both are positive is explained. The effects of secondary emission in producing blocking and influencing efficiency are discussed.

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THE EFFICIENCY OF THREE-ELECTRODE TUBES USED FOR THE PRODUCTION OF CONTINUOUS WAVES IN RADIO TELEGRAPHY, THAT IS, FOR THE CONVERSION OF DIRECT CURRENT INTO ALTERNATING CURRENT*

By

Marius Latour and H. Chireix

(Paris, France)

It is known that the anode-circuit efficiency of three-electrode tubes operating as alternating current generators, and in particular as generators of radio frequency currents such as used in radio telegraphy, may, with appropriate adjustments, practically attain 70 to 80 percent and thus exceed the value of 50 percent which, at first sight, appears as the theoretical limit attainable only when the tubes operate at full power and assuming that they have rectilinear characteristics.[1]

It does not appear to the authors that there has so far been given a precise mathematical explanation of this situation. The object of the present note is to furnish such an explanation.

Let us first consider the case wherein the generated alternating current wave shape is not taken into account, but in which the object is to supply maximum alternating power to a resistance. We shall later on consider the case wherein pure sinusoidal wave shape power only is admitted and sought. It shall be shown that, even in the latter case, high efficiency may be obtained by appropriate adjustments.

For the sake of clearness, let us assume in both cases that the tube operates with separate grid drive.

Case 1—The arrangement is that shown in Figure1, wherein:

S represents a source of alternating current of any wave shape whatever;

e represents a negatively connected battery the function of which is to shift the operating point.

*Received by the Editor, June 11, 1923.

[1] This theoretical 50 percent efficiency follows from theoretical researches on amplifiers by assuming that the output resistance load is equal to the internal tube resistance and that maximum power is drawn from the amplifier tube. (See Latour, "London Electrician," December 1, 1916.)

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E represents an anode battery of V volts which feeds the tube through the parallel arrangement of a choke L having a large inductance-to-resistance ratio working as an auto-transformer at the terminals of which is branched the load resistor r.

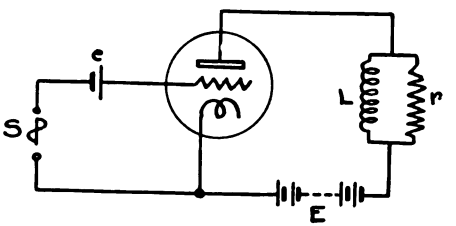

FIGURE 1

Let i be the instantaneous value of the anode current which may be of any wave shape whatever. We shall set out three relative values of this current:

1_o the maximum value $i_{max.}$

2_o the mean value $\frac{1}{T}\int_o^T i\,dt = i_{mean}$

3_o the effective value $\sqrt{\frac{1}{T}\int_o^T i^2\,dt} = i_{eff.}$

The mean current i_{mean}, which is a direct current, passes thru the choke L. The oscillating current which, at a given moment, passes in the resistor r is $(i - i_{mean})$. It may easily be shown that the oscillating power given out in the load resistor r is, as a result, exactly $r\,(i^2_{eff.} - i^2_{mean})$. The power supplied by the battery E is $(V\,i_{mean})$. The efficiency is therefore:

$$\eta = r\,\frac{i^2_{eff.} - i^2_{mean}}{V\,i_{mean}}$$

Let us suppose that the tube operates with a maximum current $i_{max.}$ equal to the saturation current of that particular working characteristic. It is also assumed that this maximum current $i_{max.}$ occurs simultaneously with the maximum positive grid potential. The voltage applied between the anode and cathode is therefore:

$$V - r\,(i_{max} - i_{mean}) = \epsilon \qquad (1)$$

It being taken that the tube operates at full power, the voltage ϵ may be found with fair exactness. It represents the voltage required to absorb the electronic current $i_{max.}$ when the

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grid is saturated. Practically, ϵ is very small in comparison with V. This implies that the maximum oscillating power is given out when the maximum oscillating voltage is practically equal to the anode battery voltage.

The resistance r must so be chosen that:

$$r\,(i_{max.} - i_{mean}) = V - \epsilon$$

that is

$$r = \frac{V - \epsilon}{i_{max.} - i_{mean}}$$

The efficiency may then be expressed by:

$$\left(i - \frac{\epsilon}{V}\right)\left(\frac{i^2_{eff.} - i^2_{mean}}{i_{max.} - i_{mean}}\right) = \left(1 - \frac{\epsilon}{V}\right)\left(\frac{\frac{i^2_{eff.}}{i^2_{mean}} - 1}{\frac{i_{max.}}{i_{mean}} - 1}\right) \qquad (2)$$

The efficiency may be determined as long as ϵ and the anode current wave-shape are known. The wave-shape may be ascertained experimentally by the use of either a reflection oscillograph or of a Braun tube. Let us examine a few particular cases:

(a)To begin with, the highest efficiency operation would be that in which the source S would have an electromotive force curve of such a shape that the grid voltage would abruptly become positive and thus remain constant during half a cycle and then suddenly negative and thus remain constant during the other half cycle.

For an appropriate setting of the battery ϵ, the anode current would alternately take the values 0 and $i_{max.}$ (See Figure 2)

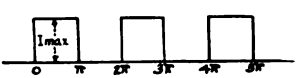

FIGURE 2

In that case, equation 2 gives us the expression:

$$\eta = \left(1 - \frac{\epsilon}{V}\right)$$

which approaches 1 for a negligible value of $\frac{\epsilon}{V}$.

(b) Another case which more closely approaches that met in practice is that in which the anode current is made up of half-sinusoids and is annulled during a whole half-cycle (Figure 3).

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FIGURE 3

This shape of current is practically obtained by a proper setting of the battery ϵ, together with sinusoidal grid excitation. By applying formula 2 to the latter case, we obtain:

$$\eta = \left(1 - \frac{\epsilon}{V}\right)\left(\frac{\frac{\pi^2}{4} - 1}{\pi - 1}\right) = \left(1 - \frac{\epsilon}{V}\right)\left(0.69\right)$$

(c) Lastly, the theoretical and classical case in which the anode current assumes the shape $\frac{1}{2}(1 + sin\,\omega t)$ (see Figure 4) gives:

$$\eta = \left(1 - \frac{\epsilon}{V}\right)\left(0.5\right)$$

This latter case therefore prevents efficiencies exceeding 50 percent.[2]

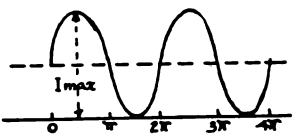

FIGURE 4

CASE II.—Efficiency in oscillating power of pure frequency, void of harmonics.

We shall modify the arrangement of Figure 1 as shown in Figure 5 by adding a condenser C in shunt to the choke L. In the present case, we will assume the choke L to have a small inductance such that it may form, with the condenser C, assumed to have a large capacity, a circuit tuned to the fundamental frequency. Furthermore, the oscillatory circuit L C, is supposed to be without losses. Under these conditions, if we consider the anode current function in terms of a Fourier series, it may be seen that the mean current (i_{mean}) passes thru the choke L just as in the preceding case and that the anode current harmonics mainly take the path of the condenser C whilst the resistor r is traversed by the fundamental frequency current only. From the fundamental current point of view, the circuit L C behaves

[2] Exactly 0.50 efficiency is found by admitting that the maximum oscillating voltage is equal to the anode battery voltage just as the maximum oscillating current is equal to the mean direct anode current.

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like an infinite resistance. On the other hand, the harmonics hardly give rise to any voltage across the condenser C. If the foregoing diagram be modified in accordance with Figure 6, by the insertion, in series with the load resistor r, of an oscillatory circuit $l\,c$ tuned to the fundamental frequency, we obtain a network which is equivalent to the ordinary arrangement wherein two separate inductively coupled oscillatory circuits are used. This amounts to saying that the arrangement corresponds to a fairly broad practical application of three-electrode tubes.[3]

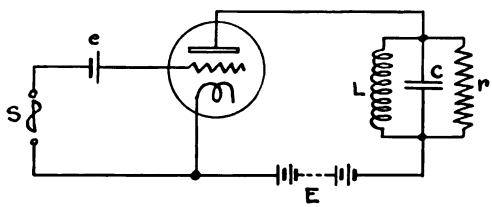

FIGURE 5

Let us continue, designating the mean current by i_{mean}, and let us also designate the amplitude of the fundamental alternating current term by $j_{max.}$

The energy consumed in the resistor r during each half cycle is

$$\frac{1}{2} r j^2_{max.}$$

assuming that the current attains its maximum value simultaneously with the grid saturation in such a manner that

$$r j_{max.} = V - \varepsilon.$$

The energy consumed in the resistance r is therefore:

$$\frac{V-\varepsilon}{2} j_{max.}$$

The energy supplied by the source E being, on the other hand $V i_{mean}$, the efficiency becomes

$$\eta = \frac{1}{2}\left(1 - \frac{\varepsilon}{V}\right)\frac{j_{max.}}{i_{mean}}$$

The expression for the efficiency is particularly simple.

If we make use of the Fourier series for curves of the kind represented by Figures 2, 3, and 4, which are symmetrical about the vertical axis, we know that the fundamental term will be given by the formula:

[3] The arrangement using a single oscillating circuit comprising the aerial, as extensively utilized in small power sets, is covered by the British Latour patent number 147,462, of 1915.

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$$j_{max.} = \frac{2}{T}\int_{t_1}^{t_2} i \sin \omega t \, dt$$

the interval between t_1 and t_2 corresponding to the length of time, in a half cycle, during which there flows a current in the anode circuit.

On the other hand, we have:

$$i_{mean} = \frac{1}{T}\int_{o}^{T} i \, dt$$

the efficiency may then be expressed by:

$$\eta = \left(1 - \frac{\varepsilon}{V}\right) \frac{\frac{1}{T}\int_{t_1}^{t_2} i \sin \omega t \, dt}{\frac{1}{T}\int_{o}^{T} i \, dt}$$

Let us again consider a few particular cases.

a') $i = \frac{1}{2}(1 + \sin \omega t)$. (See Figure 4.) The numerator integral must be taken between 0 and T and its value is $\frac{1}{4}$. The denominator being $\frac{1}{2}$ the efficiency becomes:

$$\eta = \left(1 - \frac{\varepsilon}{V}\right)(0.5)$$

b') The anode current is made up of half-sinusoids and is nil during a whole half-cycle. (See Figure 3.) The numerator integral must be taken between 0 and $\frac{T}{2}$ and is expressed by:

$$\frac{1}{T}\int_{o}^{\frac{T}{2}} \sin^2 \omega t \, dt$$

Its value is $\frac{1}{4}$. The denominator integral is equal to $\frac{1}{\pi}$ and the efficiency may therefore be written down as follows:

$$\eta = \left(1 - \frac{\varepsilon}{V}\right) \cdot \frac{\pi}{4}$$

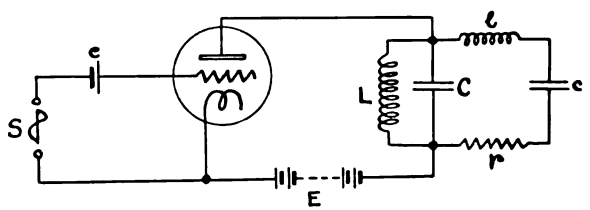

FIGURE 6

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c') A plate current of value $i_{max.}$ flows, but between certain times. (See Figure 7). The numerator integral is to be taken between the time $\frac{1}{\omega}\left(\frac{\pi}{2}-\theta\right)$ and the time $\frac{1}{\omega}\left(\frac{\pi}{2}+\theta\right)$. This integral then equals $\frac{\sin\theta}{\pi}$. The denominator integral is, on the other hand, $\frac{\theta}{\pi}$. The efficiency may therefore be expressed by:

$$\eta=\left(1-\frac{e}{V}\right)\frac{\sin\theta}{\theta}.$$

For $\theta=\frac{\pi}{2}$, the efficiency is equal to $\frac{2}{\pi}\left(1-\frac{\epsilon}{V}\right)$. It improves and aims asymptotically towards $\left(1-\frac{\epsilon}{V}\right)$ when θ decreases.

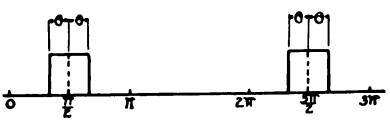

FIGURE 7

When θ is small, we obtain an impulse excitation of the oscillatory network LC, and tha particular wave-shape of the exciting current has but very little effect; it does not intervene any more than does the shape of an impulse to a pendulum in giving rise to harmonics in its motion provided that the duration of the impulse is sufficiently short.

Furthermore, it is to be remarked that the expression $\frac{i_{max.}}{i_{mean}}$, which determines the efficiency, may assume the same value k for different current wave-shapes (rectangles, triangles, parabolas, fractions of sinusoids, and so on, followed by a more or less prolonged zero period); the length of time during which the anode current flows having nevertheless to be very much shorter, relatively to the duration of the whole cycle, as k is given values closer to 1[4].

It is to be remarked that the operation with reduced plate current duration leads us to high $\frac{i_{max.}}{i_{mean}}$ ratios, that is, to the necessity of having large cathode dimensions. From that point of view, the current wave-shape might matter, for it modifies the ratio $\frac{i_{max.}}{i_{mean}}$ for a given value of k. In any case, this ratio must be

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as small as possible and even more so since ϵ is a direct function of $i_{max.}$

If we particularly consider the case c' previously described, it may be noticed that there exists an analogy between the three-electrode tube and the rotary spark gap in their respective operation. As a matter of fact, we may imagine replacing the three-electrode tube by a spark-gap which would close the circuit at the very frequency for which the oscillatory circuit $L\,C$, is tuned. From that point of view, the operation of a three-electrode tube at very high frequency is not unlike that of spark-gaps in older radio telegraphic practice.

Thruout the preceding, we have considered the three-electrode tube when operating with separate grid drive. The high efficiency operation of the tube, when using self-excitation, presents a second problem. The self-exciting arrangement must allow of obtaining, for the grid voltage, the voltage wave-shape corresponding to the high efficiencies described above. However, as this grid voltage may practically be sinusoidal, no particular difficulty will be met.

In concluding it may be said that, theoretically, three-electrode tubes constitute converters of direct current to alternating current having unforseen efficiencies.

While many radio frequency alternator efficiency figures may have been published, it might be added that but those radio frequency multipliers built by the Société Française Radio-Electrique have efficiencies which are high enough to compete with those which it is possible to obtain with three-electrode tubes.

Lastly, it is to be noted that the result of the above investigations may also be applied to magnetically controlled vacuum tubes such as those of the "magnetron" type.

[4] In particular, the case of fractions of sinusoids gives, θ having the same meaning as in c', an efficiency expression:

$$\eta = \left(1 - \frac{\epsilon}{V}\right) \cdot \frac{\theta - \frac{\sin 2\theta}{2}}{2(\sin\theta - \theta\cos\theta)}$$

This expression tends towards $\left(1 - \frac{\epsilon}{V}\right)$ when θ approaches zero and towards $\left(1 - \frac{\epsilon}{V}\right)\frac{\pi}{4}$, when θ is equal to $\frac{\pi}{2}$. With equal efficiencies θ is greater for fractions of sinusoids than for rectangles, the ratio $\frac{i_{max.}}{i_{mean}}$ being slightly higher.

SUMMARY: The theoretical limiting efficiencies of vacuum tube oscillators, for various wave forms of plate current, are mathematically investigated and discussed.

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DIGESTS OF UNITED STATES PATENTS RELATING TO RADIO TELEGRAPHY AND TELEPHONY*

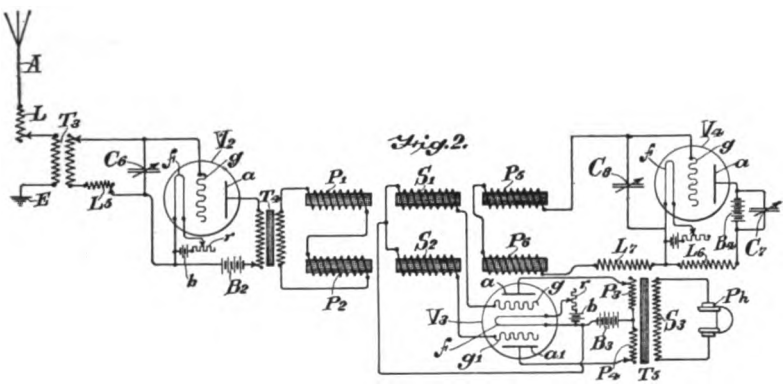
ISSUED JUNE 26, 1923–AUGUST 21, 1923

BY

JOHN B. BRADY

(PATENT LAWYER, OURAY BUILDING, WASHINGTON, D. C.)

1,459,786—D. G. McCaa, filed January 19, 1920, issued June 26, 1923. Assigned one-third to Federal Telegraph Company.



NUMBER 1,459,786—Method of and Apparatus for Electrical Communication

METHOD OF AND APPARATUS FOR ELECTRICAL COMMUNICATION, intended for radio reception without interference from static, strays or damped wave transmitters. The received currents of modulator frequency says 20,000 cycles are impressed on grids g and g^1 so that like currents simultaneously traverse the primaries $P3$ and $P4$ which, since thay are differential in their action, produce no inductive effect upon the secondary $S3$, and nothing is heard in the telephone Ph, unless the oscillator $V4$ is in operation producing oscillations of a frequency of 21,000 per second for example, whereby there are produced in the circuits of the grids g and g^1 of the thermionic device $V3$ beats of audible frequency, 1,000 per second, but dephased with respect to each

* Received by the Editor, September 4, 1923.

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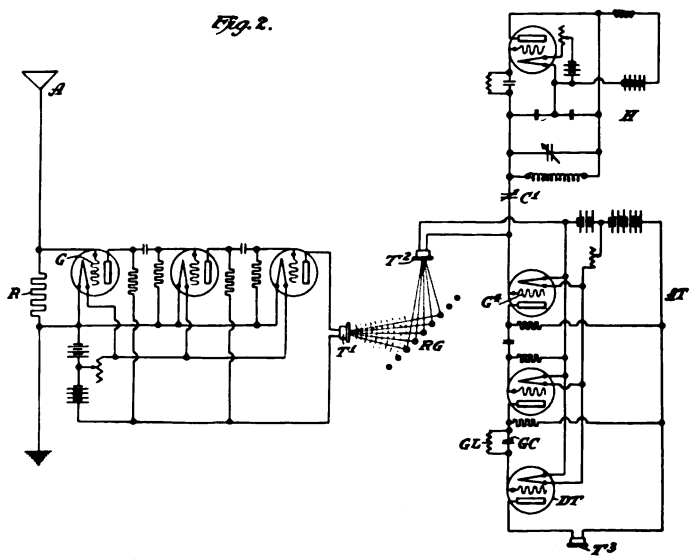
other by practically 180 degrees, causing in the primaries *P*3 and *P*4 currents dephased substantially 180 degrees, which, however because of the differential winding or connection of the primaries *P*3 and *P*4 cimulatively effect the secondary *S*3, producing in the tehephone *Ph* an audible note having a frequency of 1,000 per second which note appears for long and short periods according to the length of time the key *k* is depressed at the transmitter to form dots and dashes.

Re. 15,642—C. F. Smith et al, filed May 17, 1920, issued July 3, 1923.

Electric Condenser, particularly useful for grid condensers. The condenser is formed by thin metal foils separated by thin flexible dielectric wrapped around a relatively thin stiff body of insulating material, the ends of which project beyond the wrapping and contain terminals connected with the different sheets of foil. This invention has been previously described in these digests in connection with the original patent 1,395,931 dated November 1, 1921.

1,460,439—G. W. Pickard, filed April 22, 1922, issued July 3, 1923. Assigned to Wireless Specialty Apparatus Company.



Number 1,460,439—Interference Preventer

Interference Preventer for radio receiving systems. The

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received signal energy is converted into air waves and directed towards a reflection grating composed of elements distributed periodically in tune with the desired air wave frequency. A receiver diafram is arranged to be actuated by air waves reflected from said reflection grating. A circuit is provided for converting the currents set up by movement of said diafram into intelligible signals.

1,460,636—P. J. Armagnat, filed August 9, 1920, issued July 3, 1923.

WAVEMETER operating on the principle of comparison of an electromotive force obtained thru a coupled circuit with the difference of potential produced at the terminals of a resistance by the oscillating current to be measured.

1,460,734—W. H. Ruf, filed April 27, 1922, issued July 3, 1923.

RADIO DETECTOR formed to be carried around on the finger. A complete radio receiving set is shown in this patent having a crystal detector and a frame which fits over the finger.

1,460,801—R. H. Marriott, filed June 20, 1921, issued July 3, 1923.

DIRECTIONAL RADIO RECEIVING SYSTEM using a loop antenna circuit and a connection to earth. An electron tube circuit having its grid and filament connected with the ground connection is provided. A connection is established between the plate circuit and the loop circuit. The arrangement has the effect of repeating the loop-to-ground potential and impressing the energy upon the loop circuit.

1,461,064—De Loss K. Martin, filed February 10, 1921, issued July 7, 1923. Assigned to American Telephone and Telegraph Company.

MULTIPLEX TRANSMISSION CIRCUITS particularly adapted for radio operation wherein a carrier frequency is generated for each of three channels by modulating one frequency in accordance with another frequency, thereby producing a fundamental frequency and two side frequencies. Each of the several frequencies may then be modulated in accordance with a signal and the antenna circuit may be arranged to have a plurality of degrees of freedom corresponding to the several frequencies. At the receiving station the antenna is likewise arranged to resonate at

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each of the several frequencies, and the different modulated frequencies may be separated into channels and reduced in frequency by beating with one of the original frequencies transmitted or with a locally generated frequency. The signals are detected from the frequencies thus stepped down either by further beating by the homodyne method or straight detection method.

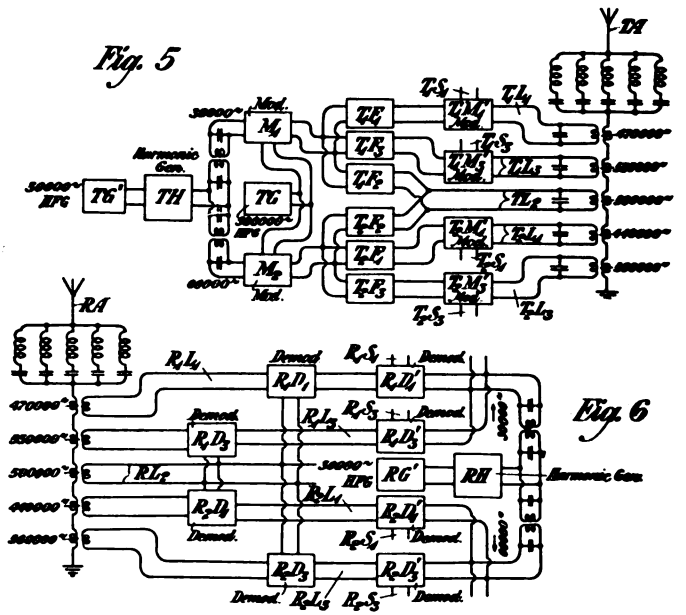

Fig. 5

Fig. 6

NUMBER 1,461,064—Multiplex Transmission Circuits

1,461,232—S. Thronsen, filed September 3, 1918, issued July 10, 1923. Assigned to Western Electric Manufacturing Company.

FILAMENT SUPPORT for electron tubes comprising a pair of resilient wires embedded in the glass press of the tube, each wire being provided with a return bend portion having its other end connected with the filament and constantly urging it taut at all times.

1,461,287—E. Pfiffner, filed January 10, 1922, issued July 10, 1923.

HIGH TENSION CONDENSER made up of a plurality of partial condensers connected in series to form a chain insulator. Each partial condenser consists of a hollow tubular supporting insu-

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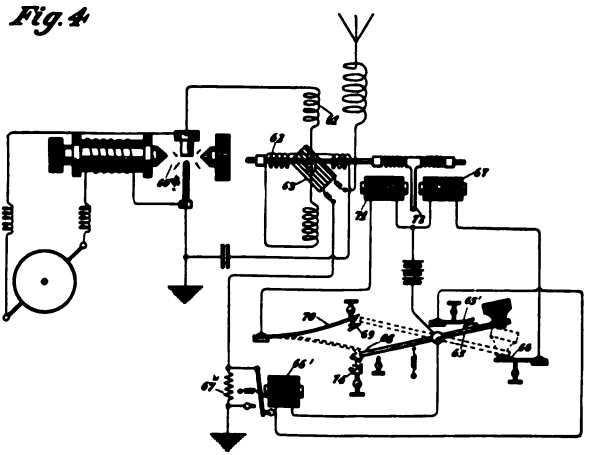
lator with conducting mounts carried by the ends of the insulator and constituting closures therefor. Metal coatings and insulating layers are arranged in and completely enclosed by the tubular insulator and conducting mounts forming elements of the condenser.

1,461,754—G. H. Clark, filed March 3, 1921, issued July 17, 1923. Assigned to Radio Corporation of America.



NUMBER 1,461,754—Transmitting and Receiving Apparatus for Radio Telegraphy

TRANSMITTING AND RECEIVING APPARATUS FOR RADIO TELEGRAPHY for more clearly defining the dots and dashes in signaling and eliminating the "tailing-off effects" in signals at the end of each dot or dash. A circuit is provided for annulling this tailing-out in the receiving system which is accomplished by sending out a counter wave from the transmitting station that more than annuls the dying-down current at the end of each dot or dash and produces an electromagnetic wave 180° from the main wave, but this is brought into effect only at the end of each dot or dash. This opposed electromagnetic wave tends to induce a current that is out of phase with the dying-down current and the combination of the two effects results in sudden termination of the dots and dashes.

1,462,038—R. V. L. Hartley, filed December 30, 1916, issued July 17, 1923. Assigned to Western Electric Company.

MODULATING SYSTEM for radio or line wire transmission. The

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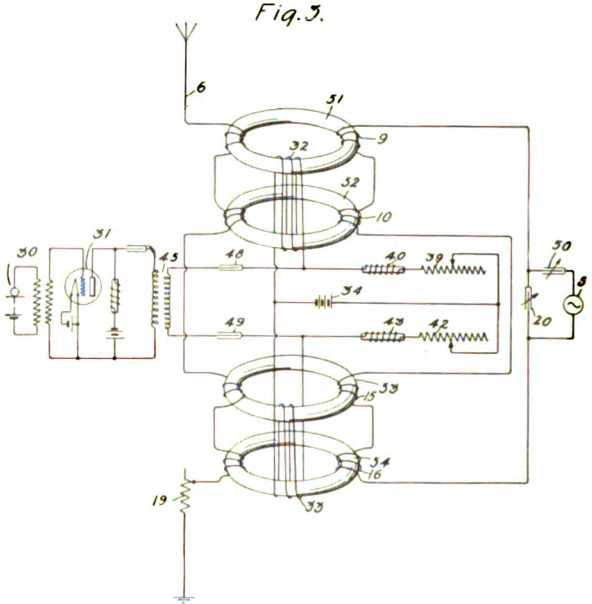
invention makes use of reactance modulators of the transformer type for controlling the radio frequency output by varying the mutual inductance between the primary and secondary windings of the transformer in accordance with a signal to be transmitted. The amplitude of the radio frequency currents radiated depends upon the coupling between the primary and secondary windings and by varying this coupling, that is, the mutual inductance in accordance with the signal, a modulation of the carrier wave is effected. The variation in coupling is effected by varying the permeabilities of the transformer cores in accordance with the signal currents. The secondary windings of the two transformers are connected to the antenna in opposition to each other, so that no radio frequency power is radiated in the absence of signaling currents. The effect of signaling currents is to increase the permeability of one transformer core, and to decrease the permeability of the other transformer core. This disturbs the balance of the opposed secondary windings, and modulated radio frequency power is radiated.

Fig. 3.



NUMBER 1,462,038—Modulating System

1,462,057—P. I. Wold, filed September 27, 1920, issued July 17, 1923. Assigned to Western Electric Company.

SWITCH MECHANISM FOR VACUUM TUBES AND THE LIKE,

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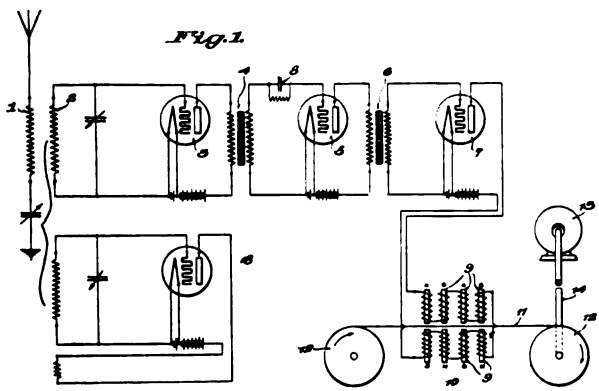
whereby a new tube is automatically cut into a circuit upon the burning out of the filament in a tube normally operating in a circuit. A relay is provided having its winding in the plate circuit of one tube and controlling the position of an armature carrying contacts which distribute connections from the tube electrodes to the associated circuits. Upon interruption of the plate current by burning out of the tube the armature moves to connect a new tube into the circuit.

1,462,882—H. Chireix, filed March 24, 1922, issued July 24, 1923.

RECEIVING SYSTEM, including an electron tube with a thermostat in the plate circuit thereof with a divided heating coil on the thermostat. A relay is arranged to disconnect a portion of the heating coil of the thermostat and an indicating device is provided which co-operates with the thermostat to respond to a signal on receipt of radio energy.

1,463,386—W. L. Carlson and E. C. Hanson, filed April 22, 1920, issued July 31, 1923.



NUMBER 1,463,386—Radio Telegraph System

RADIO TELEGRAPH SYSTEM employing a telegraphone. A plurality of electromagnets are used in conjunction with the telegraphone wire. These magnets are spaced apart in proportion to the frequency of the signals to be received and the linear speed of the recording arrangement. The plurality of magnets integrate the received signal energy over a relatively large area of the recording wire, insuring a substantial signal record.

1,463,391—E. C. Hanson and W. L. Carlson, filed February 11, 1920, issued July 31, 1923.

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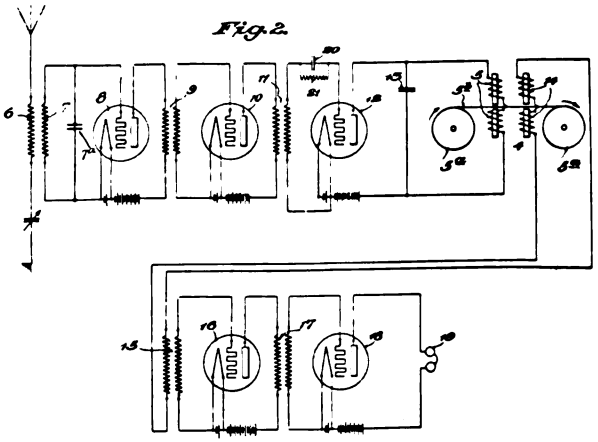

NUMBER 1,463,391—Radio Telegraph System

RADIO TELEGRAPH SYSTEM employing a telegraphone. An initial signal record is placed upon the telegraphone wire which in reproduction would tend to produce a continuous note. Incoming radio signals are caused to erase the initial record. The signals are then translated by operating the telegraphone at slow speed for reading the signals left on the wire.

1,463,554—A. N. Pierman, filed February 4, 1922, issued July 31, 1923.

MOUNTING FOR STEMS OF CRYSTAL DETECTORS of simple and inexpensive manufacture. The rod or stem which terminates in the detector whisker is supported between strands of wire made taut upon a terminal post of the detector.

1,463,797—L. A. Charbonneau, filed July 9, 1920, issued August 7, 1923.

OPTICAL TELEGRAPHY, wherein signals sent out by a transmitting station may be received only by those stations for which the message is intended. Infra-red rays are emitted and are received by making of the property of these rays for extinguishing the phosphorescence of certain phosphorescent substances.

1,463,813—J. W. Harris, filed December 29, 1916, issued August 7, 1923. Assigned to Western Electric Company, Incorporated.

ELECTRON EMITTING CATHODE AND PROCESS OF MANUFACTURING THE SAME, which comprises the applying of coatings of

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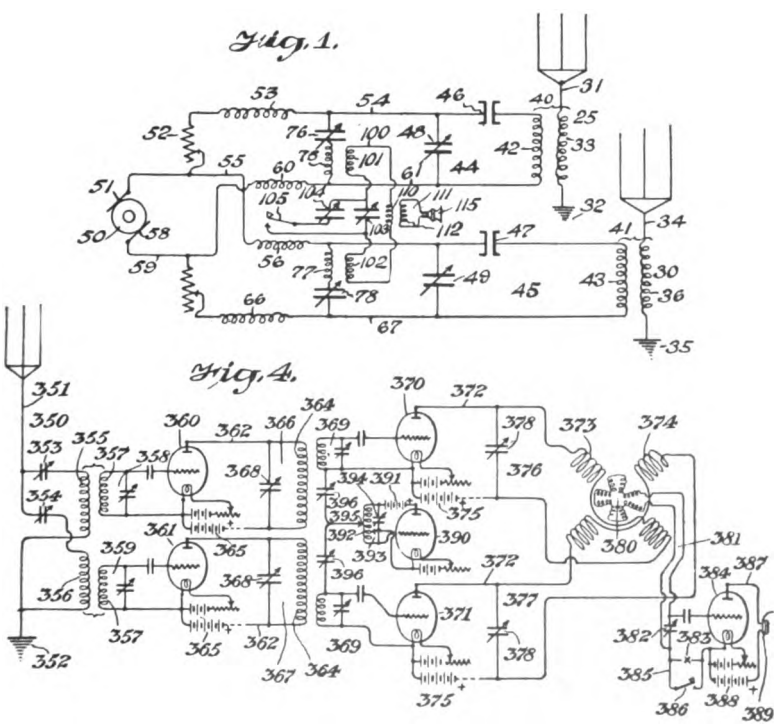
mixed barium, strontium, and calcium compounds to the filament conductor. A platinum compound is distributed between the coatings. The barium, strontium, and calcium compounds are then reduced to their oxides and the platinum compound is reduced to platinum.

1,463,860—W. Wilson, filed July 22, 1920, issued August 7, 1923. Assigned to Western Electric Company, Incorporated.

ELECTRON DISCHARGE DEVICE having its electrodes arranged for operation of the tube at high power where high temperature will have no detrimental effects on the tube construction. The lead-in wires for the grid and the anode are positioned away from the lead-in wires for the cathode and are sealed in between flare of the press and the neck of the tube.

1,463,994—J. H. Hammond, Jr., filed February 15, 1918, issued August 7, 1923.



NUMBER 1,463,994—System for the Transmission and Reception of Radiant Energy

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System for Transmission and Reception of Radiant Energy, which consists in transmitting a plurality of series of waves in such manner as to maintain a predetermined phase relationship among a plurality of the series and then modifying the phase relationship and causing the functioning of a receiving device as a result of the modification of said phase relationship whereby secret transmission may be secured.

1,464,083—S. Loewe, filed March 19, 1921, issued August 7, 1923. Assigned to Western Electric Company, Incorporated.

Receiving Apparatus for Radio Frequency Signaling, comprising a coil antenna connected with the receiving apparatus with a source of locally produced oscillations connected directly across a portion of the coil antenna.

1,464,086—W. E. Beatty, filed December 27, 1918, issued August 7, 1923. Assigned to Western Electric Company, Incorporated.

Method of and Means for Secret Signaling, wherein a plurality of different signaling waves are employed and each modified in accordance with a particular group of signals which when combined at the receiver produce an intelligent sequence of signaling.

1,464,097—R. A. Heising, filed August 7, 1920, issued August 7, 1923. Assigned to Western Electric Company.

Two-way Signaling System for radio operation in which the transmitter and receiver are permanently associated with the same circuits and the response of the receiver to energy in the local transmitter circuit is substantially reduced or eliminated.

1,464,104—A. McL. Nicolson, filed July 26, 1917, issued August 7, 1923. Assigned to Western Electric Company, Incorporated.

Selective Apparatus for Signaling Circuits, comprising an electron tube construction wherein the anode is separated by a dielectric from the grid electrode and the filament. The dielectric may be in the form of a sheet which encloses the grid electrode. The tube is connected in a circuit which has at times substantially zero space curren twith means responsive to an impressed alternating current to establish the space current.

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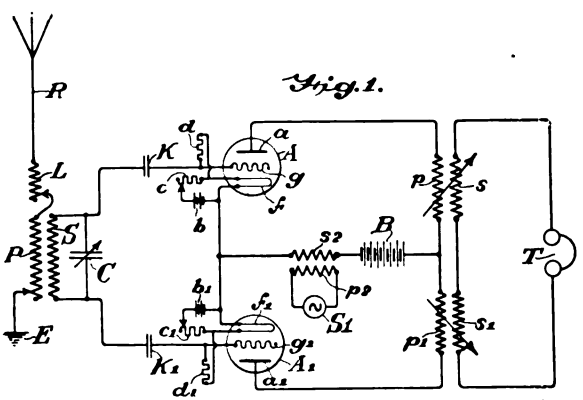
1,464,124—W. Wilson, filed July 26, 1917, issued August 7, 1923. Assigned to Western Electric Company, Incorporated.

THERMIONICALLY ACTIVE SUBSTANCE AND METHOD OF MAKING THE SAME, comprising the heating of a metallic filament in a vacuum and sputtering a coating of an alkaline earth oxide on to the filament in the vacuum, and then baking the coated filament in the vacuum.

1,464,168—W. T. Booth, et al, filed July 9, 1917, issued August 7, 1923. Assigned to Western Electric Company, Incorporated.

ANTENNA SYSTEM for airplane radio operation. An automatic reeling device is provided whereby a motor is operated to reel out the antenna to a predetermined distance for signaling and automatically retracting the antenna after the signaling is completed.

1,464,322—F. A. Kolster, filed November 26, 1920, issued August 7, 1923. Assigned one-third to Cornelius D. Ehret.



NUMBER 1,464,322—Radio Receiving Method and Apparatus

RADIO RECEIVING METHOD AND APPARATUS particularly designed for continuous wave signaling where a local source of audible frequency energy operates the signal responsive device when a signal is being received. When no signal is being received the source S^1 will cause impression upon the circuit of the telephone T of a current which would produce a response whereby if it were not for the fact that the couplings p, s and p^1

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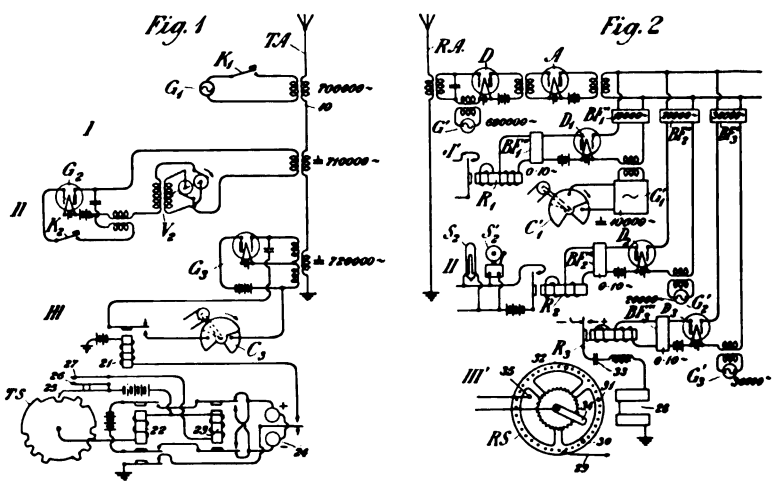
s^1 produced, by suitable winding or mode of connection, equal and opposite effects upon the circuit of the telephone T. Accordingly, when no signal is being received the source of S^1 has no effect upon the telephone T. When, however, continuous signal waves are received, the circuit S C being attuned thereto, as well as the antenna circuit, opposite ends of the inductance or secondary S will attain widely different potentials, the potential of the grid g rising for example, while the potential of the grid g^1 falls. The current in one anode circuit therefore greatly increases, while the other greatly diminishes, and accordingly the net effect of the couplings p, s and p^1, s^1 no longer is zero, and there is transferred to the circuit of the telephone T current which causes its response evidence by the production of a sound, the frequency of which is equal to or corresponds with the frequency of the current delivered by the source S^1.

1,464,533—S. Loewe, filed August 26, 1921, issued August 14, 1923.

Radio Receiving System employing an antenna system which is connected with a receiving amplifier. A source of local oscillation is connected with the input circuit of the receiving amplifier and conductively connected with the antenna system and with said input circuit.

1,464,565—L. Espenschied, et al, filed April 13, 1921, issued August 14, 1923. Assigned to American Telephone and Telegraph Company.



Number 1,464,565—Call System for Radio Telephony

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CALL SYSTEM FOR RADIO TELEPHONY, in which control apparatus is shown which is extremely selective for the purpose of preventing interference due to static or other causes. To actuate a ringing circuit at the receiver the ringing frequency is periodically varied at a sub-audible rate over a range such that the frequency coincides with the locally produced frequency at periodic intervals.

1,465,108—E. F. W. Alexanderson, filed September 16, 1918, issued August 14, 1923. Assigned to General Electric Company.

UNI-DIRECTIONAL RADIO RECEIVING SYSTEM which permits the receiving of signals of any desired wave length at a receiving station to the exclusion of other signals having the same wave length coming from directions other than that which the desired signals come.

1,465,264—F. G. Goldstone, filed September 14, 1920, issued August 21, 1923. Assigned to Joseph Frances Bernard and John Bruce Bolitho, of London, England.

ELECTRIC CONDENSER, comprising a set of stationary and rotatable plates which have the form of a shell or cup. The movable elements having the appearance of hemispheres and intermeshed with the stationary elements to vary the capacity of the condenser.

1,465,357—R. A. Heising, filed September 27, 1919, issued August 21, 1923. Assigned to Western Electric Company.

RADIO COMMUNICATION system wherein more than one radio message may be transmitted and received simultaneously. The transmitter is modulated at separate modulation frequencies and these may be simultaneously received and caused to interact at the receiver with a locally produced frequency of such value that a resultant radio frequency wave is produced which is in effect a carrier frequency and still inaudible. The frequencies are then separated, selected, and detected to obtain the separate speech components.

1,465,358—R. A. Heising, filed September 29, 1919, issued August 21, 1923. Assigned to Western Electric Company.

SIGNALING by multiplex method in radio wherein interference, due to certain parasitic and undesirable waves of certain frequencies is eliminated. A plurality of carrier waves is trans-

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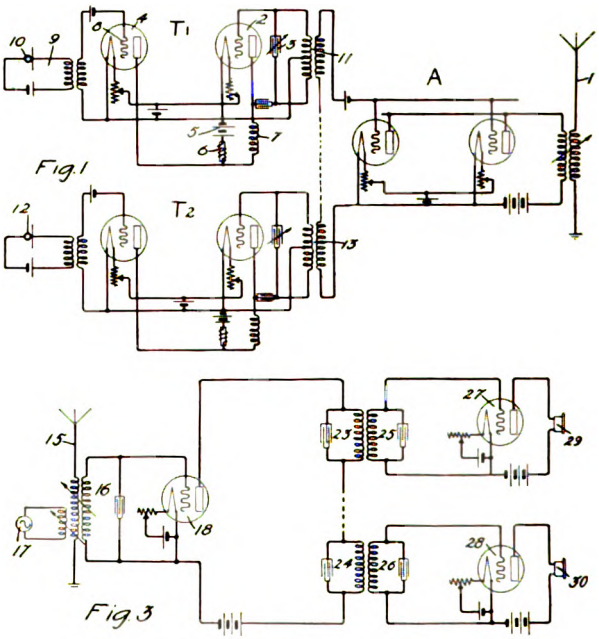
mitted from the transmitting station, each being modulated in accordance with speech. Normally the carrier waves have frequencies differing too slightly to be efficiently selected at a receiving station. Therefore a wave of a frequency differing from any of the carrier waves is transmitted along with the carriers and combined at the receiver with each of the carriers to produce at the receiver speech modulated waves of such characteristics as to be readily separated.



Number 1,465,357—Radio Communication

1,465,394—W. H. Housekeeper, filed November 6, 1920, issued August 21, 1923. Assigned to Western Electric Company, Incorporated.

Control Apparatus for Evacuated Vessels for measuring gas pressure by observing the ionization of the gas. Fluctuations in gas pressure within the electron tube give corresponding fluctuations in the intensity electron discharge from the heated filament. A circuit is shown in this patent wherein a relay under control of the anode circuit, and hence the electron stream, operates to short-circuit the cathode for regulating the electron stream.

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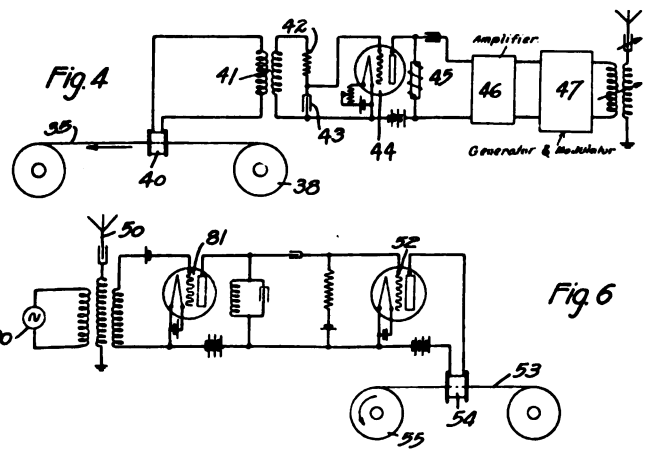
1,465,381—R. F. Trimble, filed November 4, 1918, issued August 21, 1923. Assigned to Western Electric Company, Incorporated.

GRID ELECTRODE AND ITS CONSTRUCTION, wherein a pair of supporting wires are provided bent upon themselves to form an arched portion with the ends of the wires welded and cross wires extending between the supporting wires framing the grid structure in a cage-like frame.

1,465,732—R. A. Heising, filed September 23, 1919, issued August 21, 1923. Assigned to Western Electric Company.



NUMBER 1,465,732—System of Communication

SYSTEM OF COMMUNICATION, wherein traffic handled thru a radio channel may be increased more nearly to compete with the quantity of traffic which can be handled over land lines and cables. A system for storing the signals is provided, employing the telegraphone. The signals to be transmitted may be impressed on the telegraphone record in a forward direction and then transmitted from the storage element in a reverse direction. The transmitted signals may be received at a distant receiver on a storage element, such as a telegraphone wire in the same reverse direction. The signals may then be translated for the purpose of reading by operating the telegraphone record to reproduce the signals in a forward direction.

LIST OF RADIO TRADE MARKS PUBLISHED BY THE PATENT OFFICE PRIOR TO REGISTRATION

(The numbers given are serial numbers of pending applications):

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169,626—"DOMESTIC" for telephone receivers. The Domestic Electric Company, Cleveland, Ohio. Claims use since about May, 1922. Published July 10, 1923.

171,473—"SATURN" in ornamental design for telephone jacks for telephone receivers. Saturn Manufacturing Company, New York, N. Y. Claims use since August 18, 1922. Published July 10, 1923.

173,956—"GLORAD" for radio transmitting and receiving sets. Globe Radio Manufacturing Company, New York City. Claims use since May 22, 1923. Published July 10, 1923.

178,282—"RA-MO-PHONE" for cabinets for radio receivers, motion picture machines and phonographs. Radio Motion Picture Phonograph Corporation, Long Island City, New York. Claims use since December 1, 1922. Published July 10, 1923.

171,135—"MOGUL DRY-STORAGE BATTERIES" in ornamental design for storage batteries. Mogul Electric Company, Seattle, Washington. Claims use since July 1, 1922. Published July 31, 1923.

171,142—Elements of Audion in ornamental design for radio transmitting and receiving sets. Bruno Radio Corporation, New York City. Clains use since July 1, 1922. Published July 31, 1923.

179,976—"WEARITE STORAGE BATTERY" in ornamental design foi storage batteries. Wearite Storage Battery Company, Philadelphia, Pennsylvania. Claims use since March 10, 1923. Published July 31, 1923.

180,142—"RAJAH" for radio receiving sets. Rajah Radio Guild, University City, Missouri. Claims use since March 15, 1923. Published July 31, 1923.

171,275—"TWIN ADAPTER" for connector plugs for radio telephone and telegraph apparatus. Pacent Electric Company, Incorporated, New York City. Claims use since not less than one year. Published July 31, 1923.

180,279—"GERACO" in ornamental design for radio reeciving apparatus. General Radio Corporation, Philadelphia, Pennsylvania. Claims use since May 1, 1922. Published August 7, 1923.

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166,124—"PIANOLA" for radio transmitting and receiving sets. The Aeolian Company, New York, N. Y. Claims use since prior to June 14, 1922. Published August 21, 1923.

179,567—"SENSITONE" in ornamental design for radio transmitting and receiving apparatus. Harold R. Wakem and Company, Chicago, Illinois. Claims use since September 1, 1922. Published August 21, 1923.

179,630—"PICK OF THE MARKET RADIO" in ornamental design for radio receiving apparatus. George Kenneth Thompson, Boston, Massachusetts. Claims use since on or about April 13, 1923. Published August 21, 1923.

180,140—"A K" in ornamental design for radio receiving apparatus. Atwater Kent Manufacturing Company. Claims use since on or about March 1, 1922. Published August 21, 1923.

180,706—"THE ROYALTY OF RADIO" for radio receiving sets. The Colin B. Kennedy Company, St. Louis, Missouri. Claims use since April 1, 1923. Published August 21, 1923.

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PROCEEDINGS OF
The Institute of Radio Engineers

Volume 11 DECEMBER, 1923 Number 6

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RECEIVING MEASUREMENTS AND ATMOSPHERIC DISTURBANCES AT THE BUREAU OF STANDARDS, WASHINGTON, D. C., MAY AND JUNE, 1923*

By

L. W. Austin

(Chief, Radio Physical Laboratory, Bureau of Standards)

(Communication from the International Union for Scientific Radio Telegraphy)

At the end of April, Lafayette Station increased its frequency for the U. R. S. I. signals at 3 P. M., E. S. T.,[1] to 16.2 kilocycles (18,500 m.), tho continuing to send occasionally on 12.8 kilocycles (23,400 m) at other times. This change was not known here, however, until May 11, consequently no observations were obtained at 3 P. M. during the first part of that month.

It was also found that Lafayette, which had been heard very irregularly at 10 A. M. for several months past, could be depended upon with considerable certainty between 8 and 9 A. M. Accordingly, on June 1, the observation time was shifted to the earlier hour and measurements made both in the morning and afternoon on the 16.2 kilocycles (18,500 m.) wave.

The observations for May and June show a greater difference in strength between the two stations than was found in the corresponding months of last year, Lafayette being stronger during the morning (all daylight signal path) and showing much less afternoon fading than last year; while Nauen is weaker in the morning and fades badly in the afternoon, averaging about the same in intensity as in the corresponding period of 1922. This year's observations on Nauen's fading are much more reliable than those of a year ago, on account of more accurate information regarding the times of transmission on afternoons when the signals could not be heard.

The atmospheric disturbances at Nauen's wave length are approximately the same, while the disturbances corresponding to

* Published by permission of the Director of the Bureau of Standards of the United States Department of Commerce. Received by the Editor, August 15, 1923.

[1] Eastern Standard Time (Washington).

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Lafayette's signals, partly at least due to the change in wave length, average about half the strength of last year.

As was pointed out in the resume of last year's results, the Hertzian term of the transmission formula, if the curvature of the earth be taken into account, should have the great circle distance between the sending and receiving points replaced by $r \sin \phi$, where r is the radius of the earth and ϕ the angle between the two stations as seen from the earth's center. This correction amounts to about 20 percent for the distance Washington to Berlin.

The calculated A. M. intensities (all daylight between stations), assuming 480 amperes for Lafayette at 16.2 kc. (18,500 m.) and 380 amperes for Nauen (24.0 kc. or 12,500 m.) are according to the formula:

E (Lafayette) $= 37.3 . 10^{-6}$ volts/meter and
E (Nauen) $= 18.5 . 10^{-6}$ volts/meter

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FIELD INTENSITY OF NAUEN AND OF DISTURBANCES $f = 24.0$ kc. ($\lambda = 12{,}500$ m.) IN MAY, 1923, IN MICROVOLTS PER METER

	10 A. .M.		3 P. M.	
Date	Signal	Disturbances	Signal	Disturbances
1	30.3	30	*	85
2	31.6	90	3.4	150
3	14.1	375	13.6	180
4	3.7	220	2	300
5	22.7	110	*	190
7	27.4	25	10.0	46
8	9.2	55	*	3000
9	29.5	26	10.6	130
10	24.0	22	5.4	55
11	51.5	50	15.9	95
12	51.5	65	2.0	260
14	10.6	220	*	340
15	12.9	70	*	350
16	25.0	180	*	250
17	47.0	20	10.0	200
18	27.8	160	12.8	100
19	47.0	45	5.0	290
21	**	60	**	160
22	**	35	*	130
23	**	120	*	290
24	**	95	*	300
25	**	50	*	150
26	**	60	**	100
28	**	25	*	180
29	37.6	20	*	300
31	18.0	290	**	350
Average	27.4	96.9	3.8	306.0

* Not heard.
** Not sending.
.... Not taken.

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FIELD INTENSITY OF LAFAYETTE AND OF DISTURBANCES $f = 12.8$ kc. ($\lambda = 23{,}400$ m.) A. M., $f = 16.2$ kc. (18,500 m.) P. M. IN MAY, 1923, IN MICROVOLTS PER METER

	10 A. M.		3 P. M.	
Date	Signal	Disturbances	Signal	Disturbances
1	**	65	....	150
2	**	145	....	230
3	**	500	....	200
4	**	540	....	450
5	**	240	....	320
7	**	55	....	95
8	70.0	100	....	3000
9	85.0	50	....	220
10	**	45	....	100
11	**	85	....	200
12	**	65	7.5***	350
14	50.0	220	14.0	450
15	**	70	16.7	380
16	**	180	40.0	460
17	**	20	72.3	220
18	**	160	78.1	130
19	**	45	60.3	320
21	**	60	43.5	210
22	**	35	56.0	160
23	**	120	53.0	310
24	**	95	21.2	350
25	**	50	66.1	185
26	**	60	52.0	150
28	**	25	33.1	200
29	72.3	20	13.0	450
31	**	290	36.2	390
Average	69.3	128.5	41.4	370.0

* Not heard.

** Not sending.

.... Not taken.

*** Lafayette began sending U.R.S.I. signals on 16.2 kc. (18,500 m.) April 28.

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FIELD INTENSITY OF NAUEN AND OF DISTURBANCES $f = 24.0$ kc. ($\lambda = 12{,}500$ m.) IN JUNE, 1923, IN MICROVOLTS PER METER

	9 A. M.		3 P. M.	
Date	Signal	Disturbances	Signal	Disturbances
1	27.8	50	*	380
2	19.8	250	*	400
4	19.2	8.5	**	150
6	18.5	42.5	*	320
7	15.3	160	**	180
8	27.8	52	*	150
9	13.8	15	10.7	100
11	12.9	20	13.2	65
12	19.2	15	*	45
13	25.6	15	9.9	20
14	22.9	50	19.0	100
15	**	40	*	250
16	19.2	90	....	....
18	25.6	20	2.0	350
19	32.0	38	2.0	280
20	34.2	25	2.0	390
21	47.0	150	*	250
22	26.0	60	13.8	150
23	32.0	18	....	....
25	34.0	30	16.5	300
26	23.6	75	**	405
27	30.0	80	2.0	250
28	25.8	63	....	150
29	34.0	43	23.0	130
30	21.0	25	....	....
Average	25.3	57.4	6.3	219.0

* Not heard.
** Not sending.
.... Not taken.

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... OF LAFAYETTE AND OF DISTURBANCES
= ... 0 m.) IN JUNE, 1923, IN MICROVOLTS PER METER

	9 A. M.		3 P. M.	
	Signal	Disturbances	Signal	Disturbances
	**	60	42.3	430
2	114.0	300	*	460
4	**	125	34.0	230
6	108.0	80	2.0	330
7	126.0	150	49.8	3000
8	132.0	65	34.5	210
9	160.0	30	60.2	150
11	114.0	25	57.3	80
12	120.0	15	59.0	45
13	120.0	48	102.0	60
14	66.5	75	78.0	150
15	108.0	80	57.3	380
16	96.2	100	....	....
18	132.0	28	72.3	360
19	72.3	45	19.0	300
20	126.0	30	38.8	450
21	108.0	180	60.0	300
22	120.0	85	84.0	180
23	126.0	25	....	....
25	132.0	38	84.0	310
26	84.0	85	2.0	450
27	108.0	100	78.0	300
28	126.0	80	72.2	150
29	90.0	50	....	130
30	102.0	30	....	....
Average	112.5	77.2	56.5	383.0

* Not heard.
** Not sending.
.... Not taken.

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RATIO OF AVERAGES

f kilocycles)	λ (meters)	Signal P.M. / A.M.	Disturbance P.M. / A.M.	A.M. Signal / Disturbance	P.M. Signal / Disturbance
		May			
12.8 A.M.	23,400 A.M.	0.60	2.90	0.54	0.11
16.2 P.M.	18,500 P.M.				
24.0	12,500	0.14	3.14	0.28	0.012
		June			
16.2	18,500	0.50	5.0	1.46	0.15
24.0	12,500	0.25	3.8	0.44	0.029

SUMMARY: The signal strength of the Lafayette and Nauen stations and the strength of the corresponding atmospheric disturbances are given for May and June, 1923.

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RECENT DEVELOPMENTS IN HIGH VACUUM RECEIVING TUBES—RADIOTRONS, MODEL UV-199 AND MODEL UV-201-A*

By

J. C. Warner

(Research Laboratory, General Electric Company, Schenectady, New York)

The present trend in vacuum tube development is largely toward the reduction of power required for excitation of the filament and at the same time, when possible, an improvement in the operating characteristics of the tube. This development is taking place as a result of several factors, the principal of which are the discovery and application of new physical phenomena, more complete knowledge of the relation between the mechanical and electrical design of the tube, better processes for carrying out of the designs required, and a better understanding of the requirements of the circuits in which the tube is to be used.

The purpose of this paper is to illustrate these points by a brief description of two receiving tubes which recently appeared on the market—the UV-199 and UV-201-A Radiotrons.

The UV-199 is a tube intended for use as a detector or as an amplifier and is designed for dry cell operation. The UV-201-A also may be used as a detector or as an amplifier and is designed to be interchangeable with the older UV-201, but requires only one-fourth as great filament current and has noticeably better operating characteristics than the UV-201. Internal and external views of the UV-199 and UV-201-A are shown in Figures 1 and 2.

Both of these tubes contain a new type of filament known as the X-L tungsten filament. Compared with the older tungsten filaments, the X-L filament operates at a much lower temperature, has a higher electron emission efficiency and a longer life. Another important but less apparent advantage is that for a given voltage and current, and at the normal operating temperature, the X-L filament is longer than the old type tungsten fila-

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ment. This has considerable influence on the design of the tube, as will be seen later.

Coincident with the introduction of the X-L filament, new exhaust processes have been developed which serve to assure

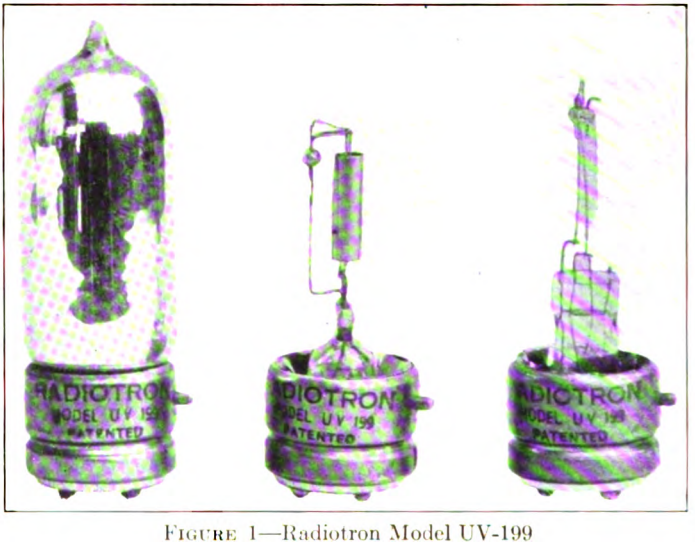

FIGURE 1—Radiotron Model UV-199

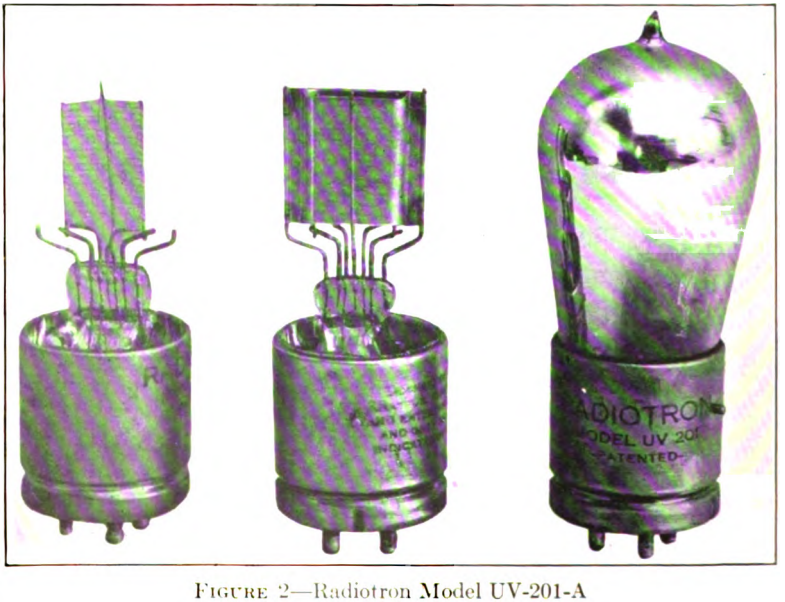

FIGURE 2—Radiotron Model UV-201-A

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an extremely good vacuum in tubes containing the new filament. The typical silvered or colored appearance of the UV-199 and UV-201-A is incidental to these exhaust processes.

The filament of the UV-199 is conveniently operated from three dry cells in series as the filament rating is 3.0 volts and 60 milliamperes or 0.18 watt. The advantages of this rating are readily seen after a brief consideration of dry battery characteristics. Dry batteries are most efficient at small current loads; hence, for a given power it is most economical to draw this from the battery at a low current rate. Thus, the small current required by the UV-199 gives it an important advantage over other tubes in battery economy. The second requirement for best battery efficiency is that the battery be used until the closed-circuit voltage has fallen to one volt or less per cell, that is, the end-point of the cell should not be greater than one volt. The use of three cells in series on the UV-199 filament meets this requirement perfectly.

Figure 3 shows characteristics of an average "general purpose" dry cell which plainly indicate the advantage both of a low current rate and a low end-point.

Where it is desired to construct a receiving set of minimum size and weight, for instance for portable use, flashlight cells may be used for filament excitation. An ordinary three-cell

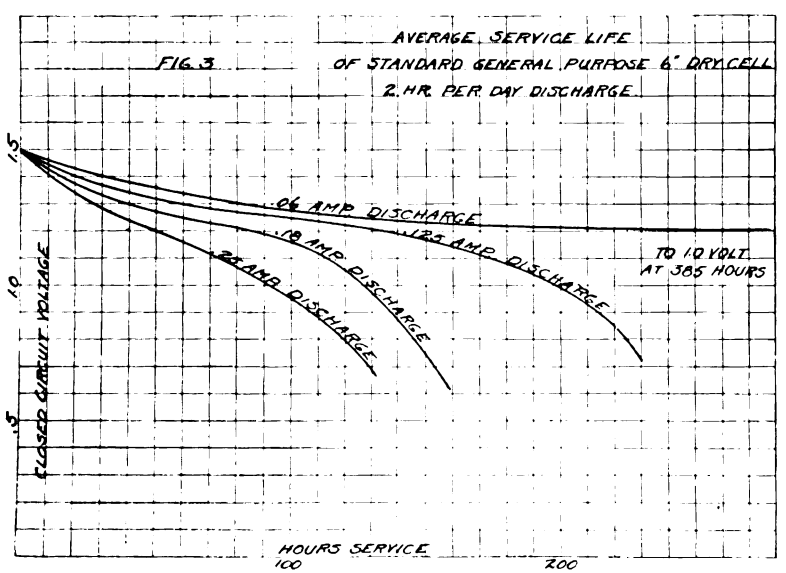

FIGURE 3

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tubular battery will operate a one-tube set one hour per day for approximately one month. The economy of such operation is naturally less than when standard six-inch cells are used, but this is relatively unimportant in a portable equipment.

The small dimensions of the UV-199, 1 inch by 3½ inch (2.54 by 8.9 cm.), are a considerable advantage in designing portable sets as well as in the six to eight-tube combinations which are coming more and more into use.

It is, of course, important that when a tube is designed for low filament power consumption, the operating characteristics should not be sacrificed; and the UV-199, in fact, shows a substantial improvement over the UV-201 altho consuming only one twenty-seventh the amount of power in the filament. This has been made possible by careful design of the electrodes, and by the perfection of factory processes for making and assembling the various component parts, so that in spite of a relatively short filament the space charge characteristics are better than in many larger tubes.

Figures 4 to 7 show some of the usual characteristics of the UV-199 and UV-201-A, and for comparison, the corresponding curves on the UV-201 are given.

In general, the UV-199 may be used in any of the usual receiving tube circuits, and requires no special adjustments other than suitable filament voltage control. On account of the low filament current, the rheostat resistance must be considerably higher than is required by the older one-ampere filaments. For example, a single tube operated from dry cells requires a thirty-ohm rheostat.

As a detector, the UV-199 operates most satisfactorily with approximately 40 volts on the plate altho critical adjustment of plate voltage is never required. Slightly better detector action may be obtained at 60 volts, but since the grid return is normally connected to the positive side of the filament, causing the mean grid potential to be slightly positive, the plate current becomes excessive at the higher plate voltage.

As an audio frequency amplifier, the tube may be used with plate voltages up to 100 if suitable negative grid bias is provided. This bias is approximately the same as is required by any amplifying tube which is expected to operate with comparatively high input voltages, and varies from 3.0 volts at 60 volts plate to 6.0 volts at 100 volts plate. The most common conditions for operation are 80 volts plate and 4.5 volts grid. This combination allows reasonably distortionless amplification up to the amount

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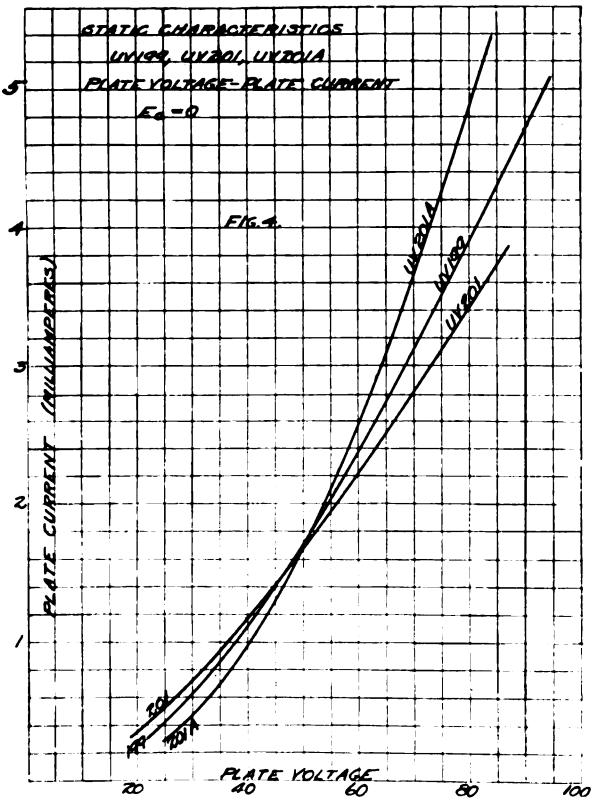

FIGURE 4

of power required to operate a loud speaker, and at the same time does not cause excessive drain from the plate battery. For head telephone reception, the higher plate voltages are unnecessary and very satisfactory results may be obtained at 40 volts. In this case a separate grid battery is unnecessary since the small bias obtained in the usual way by utilizing the voltage drop in the filament rheostat is sufficient. The purpose of this bias is to raise the input impedance of the tube to the point where it ceases to affect the terminal grid voltage, in other words to allow the total voltage induced in the secondary of the interstage transformer to be applied to the grid without loss in the windings of the transformer. A fraction of a volt is usually sufficient for this purpose.

The small elements and base of the UV-199 result in relatively low internal capacities, approximately 40 percent less than corresponding values for the UV-201. This feature is of particular

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importance when the tube is used in certain radio frequency amplifying circuits, and the utilization of the advantage of the low tube capacity is aided by the location of the grid and plate pins diagonally opposite from each other instead of adjacent, as in previous tubes. This arrangement allows short and direct connections from the tube socket to the interstage transformers or reactors. Since a grid bias other than the rheostat drop is seldom used on radio frequency amplifier tubes, and since the input voltages on the tubes are small, the most satisfactory plate voltage is usually about 40 volts.

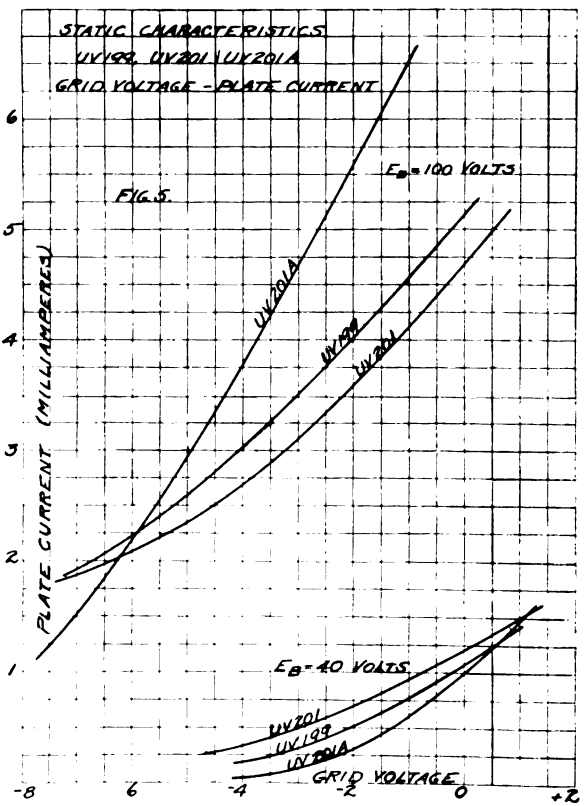

FIGURE 5

As has been mentioned before, the UV-199 is an example of a tube design in which the cathode is necessarily short, being about half the length of the UV-201 filament. In spite of this, excellent operating conditions have been obtained by careful arrangement of the other elements. In a tube of cylindrical construction, the

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space charge relation is such that the plate current at a given plate voltage is directly proportional to the effective length of the electrode structure and is inversely proportional to a function of the grid and plate diameters. Therefore, the mutual conductance of the tube, which is perhaps the best single measure of the effectiveness of the tube as an amplifier, is proportional to these same functions.

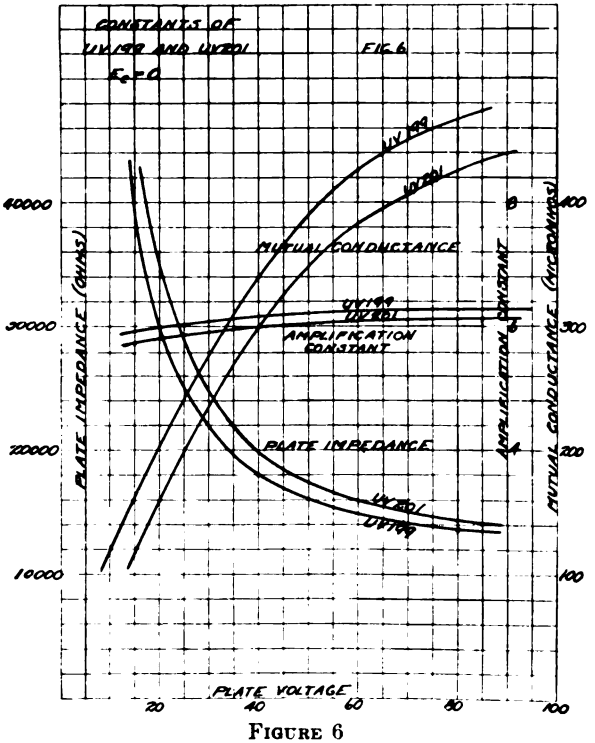

FIGURE 6

Similarly in a tube having planar structure, the mutual conductance is proportional to the effective area of the structure and inversely proportional to a function of the grid-filament and plate-filament distances.

The UV-201-A, while not having, strictly speaking, a planar structure, does owe its high mutual conductance to the large areas made effective by a long filament. The spacings, while comparatively small, are not as small as in the UV-199. This tube was designed to replace the UV-201 and besides requiring only 0.25 ampere as compared with 1 ampere for the UV-201, it

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has other marked advantages which are principally due to the desirable characteristics of the X-L filament.

The rated filament voltage of the UV-201-A is 5.0 volts, so that the tube can be used in sets designed for the UV-201 and the filament can be operated in parallel with the UV-201 filament. However, the average electron emission at this voltage is about 45 milliamperes, which is in excess of what is ordinarily needed in a receiving tube, and for this reason, it is often possible to secure excellent results with 4.0 volts or even less on the filament, particularly when 40 volts or less are used on the plate.

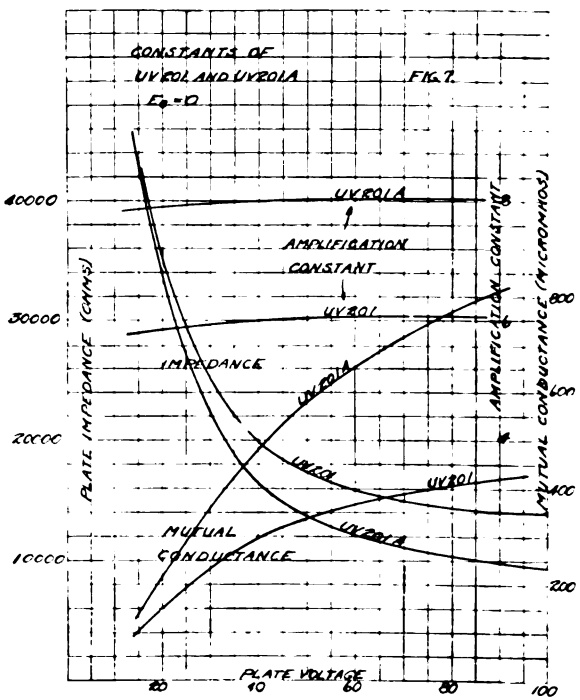

FIGURE 7

Figure 8 gives an interesting comparison of the total electron emission and the electron emission efficiency of the UV-201 and UV-201-A filaments. The great advantage of the X-L filament is shown by the fact that at normal voltage its efficiency is over twenty times as great as that of the older tungsten filament. Extensive life tests have shown that this high emission does not gradually decrease as the tube is run, but remains essentially constant until just before the end of life.

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In determining the amplification constant and the plate impedance of the UV-201-A, there were evidently two ways of making use of the large electrode areas. First, the plate impedance could have been lowered, keeping the amplification constant the same as in the UV-201, or second, the amplification constant might have been raised, and the plate impedance left unchanged.

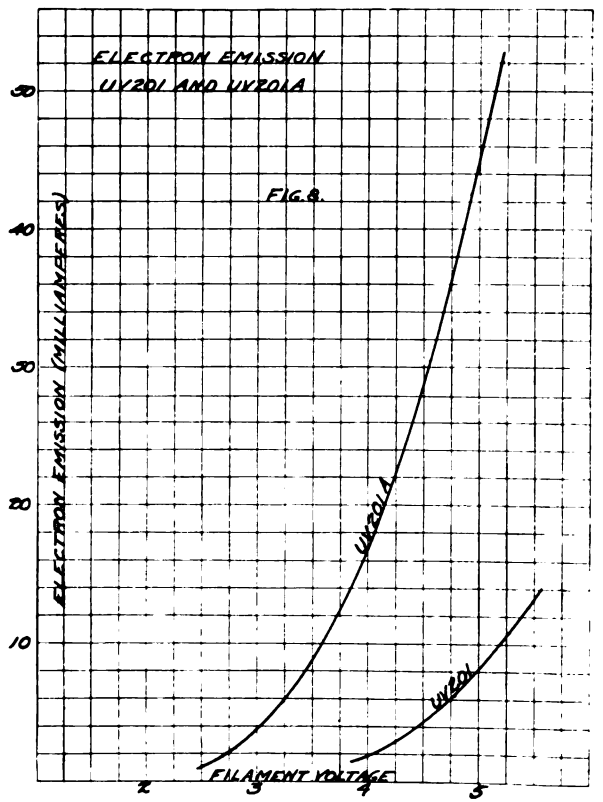

FIGURE 8

The design chosen represents a combination of these two possibilities as the amplification constant has been raised from 6 to approximately 8, and the plate impedance at 40 volts has been lowered from 20,000 ohms to approximately 16,500 ohms. The higher amplification constant serves to increase the ratio between output and input voltages, while the lower impedance aids in producing uniform amplification for all frequencies, and so reduces distortion.

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The plate and grid voltages required by the UV-201-A are the same as for the UV-199 except that when the UV-201-A is used as an amplifier, the plate voltage may be increased to 120 volts without danger of overload. In this case a negative grid bias of 7.5 to 9.0 volts should be used.

On account of the high electron emission and high mutual conductance of the tube, it is especially suited to operation of loud speakers and the power output which may be obtained at a given input voltage is over twice as great as from the UV-201.

The detector action is noticeably good for a tube of the high vacuum type, due in part to the high mutual conductance. The usual conditions for detection are 40 volts on the plate, grid leak resistance of 2 to 10 megohms, and a grid condenser of 0.00025 microfarad capacity with the grid return connected to the positive side of the filament.

One other improvement which is due to the use of the X-L filament appears in both the UV-199 and UV-201-A tubes—the almost complete elimination of tube noises. These noises in tungsten filament tubes may ordinarily be divided into two classes, a crackling noise which is characteristic of high temperature filaments, and a hissing or frying noise which is due to small traces of gas in the tube. The low operating temperature of X-L filaments of course eliminates the first class entirely and the high vacuum renders the second class almost negligible.

While the various characteristics which have been illustrated are sufficient to enable prediction of the performance of these tubes in any amplifying circuit, it is of interest to compare some of the characteristics of the tubes under typical operating conditions. Figures 9 and 10 illustrate the alternating output current and output power of the UV-199 and UV-201-A with a 20,000 ohm resistance load in the plate circuit. These curves have been plotted from actual measurements, altho they check closely the curves calculated from the familiar amplification equation.

$$I_p = \frac{\mu E_g}{R_i + R_o}$$

where I_p = alternating plate current (root-mean-square)
μ = voltage amplification constant
E_g = voltage applied to grid (root-mean-square)
R_i = internal plate impedance of tube
R_o = load resistance.

No attempt is made here to determine the relation between

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the amplitude of the fundamental component of the output current and the amplitude of any harmonics which may be present, but practice has shown that any distortion due to introduction of harmonics in the output is slight within the range of input voltages shown.

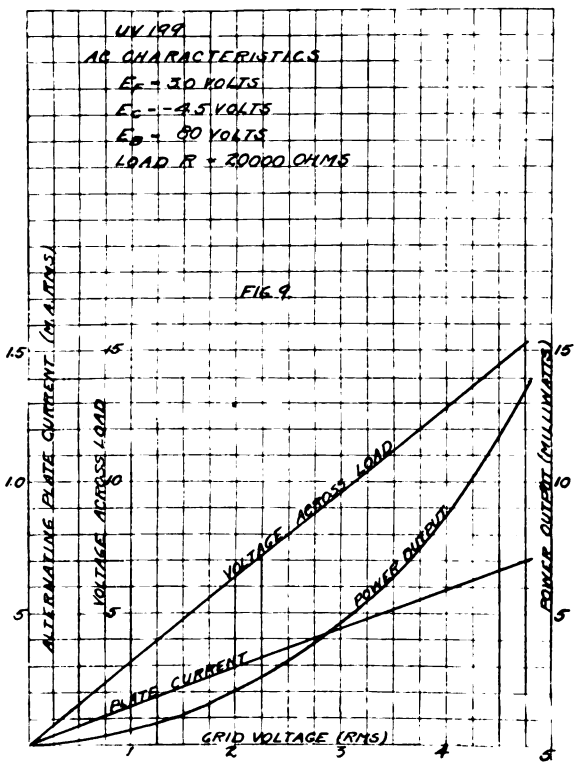

FIGURE 9

A brief consideration of the usual way of rating amplifier tubes calls attention to the need of a uniform method of rating, which will give the user of the tube or the designer of auxiliary apparatus a quantitative idea of the capabilities of the tube in the circuit for which the tube is best suited. The erroneous impression once existed, and still does to some extent, that the amplification constant of the tube was a measure of the actual amplification given by the tube in any circuit. The term itself is perhaps a misnomer, and the English term "voltage factor" would appear more suitable.

Recently the use of mutual conductance as a tube rating has

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come into use. This, of course, gives a much better idea of the capabilities of a tube than does the amplification constant, but still does not furnish nearly all of the quantitative information which is desirable. For example, a loud speaker may have a certain impedance and require a certain amount of power to give satisfactory intensity. The mutual conductance alone does not show whether the tube in question can furnish this power, because it is defined on the basis of differential quantities, while under actual operating conditions, the current and voltage amplitudes may be considerable.

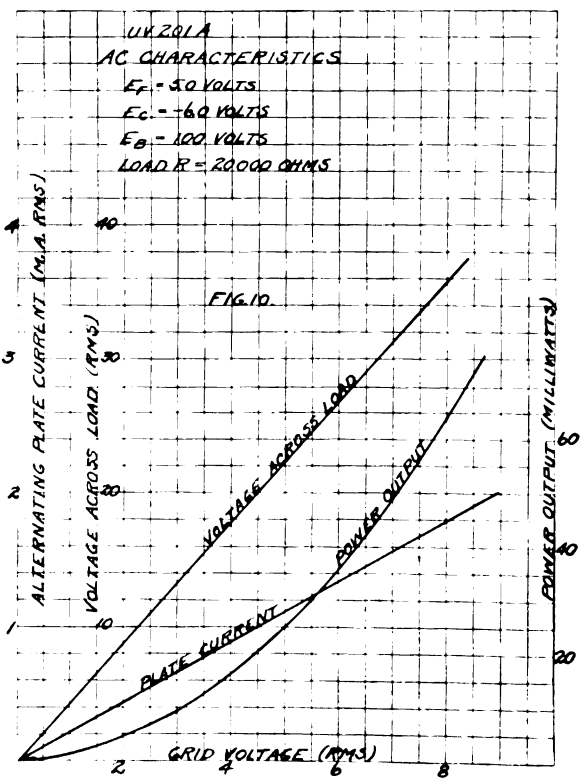

FIGURE 10

Hence, it would seem that the rating of the tube should include some such quantity as the power output in milliwatts or millivolt-amperes per volt squared input at rated plate and grid voltages, and also the maximum input voltage which can be handled without noticeable distortion, assuming the load conditions most

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suitable for the tube. Then knowing the amount of power actually required, it would become a simple matter to predict the size of tubes and number of stages of amplification required.

Such a method of rating would go far in placing the receiving tube and its associated apparatus on the same substantial basis as other older and better standardized sorts of electrical equipment.

SUMMARY: The operating characteristics of radiotrons UV-199 and UV-201-A are given, together with the general considerations which determined the design of these tubes. A method of rating receiving tubes (in place of mutual conductance) when appreciable undistorted output is required, as for loud speaker operation, is discussed.

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COMMERCIAL RADIO TUBE TRANSMITTERS*

By

W. R. G. Baker

(Radio Engineering Department, General Electric Company, Schenectady, N. Y.)

The development and design of commercial radio telephone and telegraph transmitters involves problems that cover a considerable portion of the field of radio engineering. Almost any one of the problems would make an interesting technical paper. In general, we shall consider in this paper various types of commercial transmitting equipments, the majority of which have been manufactured for the Radio Corporation of America by the General Electric Company.

Commercial transmitters may be classified according to power rating, service requirements, circuit design, and the like. For example, service classification might be as follows:

Service Classification

1. Ship Stations.
2. Shore Stations (Fixed).
   a. Ship to shore.
   b. Trans-oceanic.
3. Aircraft.
4. Portable and Miscellaneous.

Circuit Classification

1. Antenna Oscillator (Frequency determined by constants of antenna).
2. Tank Circuit.
3. Master Oscillator—Power Amplifier.
4. Miscellaneous Circuits comprising one of the preceding methods of setting the frequency combined with additional circuit features, such as side band or carrier elimination, and other more or less special arrangements.

*Received by the Editor, April 3, 1923. Presented before The Institute of Radio Engineers, New York, April 4, 1923.

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Obviously telephone equipments might be classified according to the modulation system employed, such as absorption, modulating amplifier, plate modulation, or other forms. In this paper we shall consider classification according to service, in which case we are especially interested in classes 1 and 2-a.

ET-3602 AND ET-3608 TRANSMITTING EQUIPMENTS

These transmitters were designed particularly for ship service, but of course are adaptable for fixed station use when the range requirements are within the power ratings of the sets.

ET-3602 and ET-3608 transmitters are intended to provide communication by continuous wave telegraphy, interrupted continuous wave telegraphy, and telephony. The provision for transmitting interrupted continuous waves is made in order that communication may be carried on with stations not equipped for the reception of continuous wave signals. The wave form radiated on interrupted continuous wave transmission has characteristics sufficiently close to those of a spark transmitter that stations that can receive the latter can also receive the former. Transmission by continuous waves is so much more effective than that by interrupted continuous waves and by spark signals that it is only a matter of time before all receiving stations will be equipped to receive continuous waves. When that time comes, the provision in these tube transmitters for interrupted-continuous wave telegraphy may be omitted.

The 200-watt transmitter (Figure 1) utilizes four 50-watt radiotrons (UV-203) (Figure 2), as oscillators when transmitting continuous waves or interrupted continuous waves (hence the 200-watt rating) and five for telephony (two as oscillators, two as modulators, and one as a speech amplifier). The last radiotron amplifies the output of the microphone transformer before it is impressed on the grids of the modulating tubes, since the transformer alone has not sufficient capacity to permit modulation of the output of the oscillators efficiently.

The 1,000-watt transmitter in Figure 1 utilizes four 250-watt radiotrons (UV-204) (Figure 2) as oscillators when transmitting continuous waves or interrupted-continuous waves, and four for telephony (two as oscillators and two as modulators). In this set a UV-203 radiotron is also used as a speech amplifier for telephony.

The sets have a wave length range, on an average ship's antenna, of from 300 to 800 meters, and the three methods of communication are provided for thruout this range. The set

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can also be supplied for a wave length range of 600 to 2,000 meters. Under these conditions, continuous wave and interrupted telegraphy are provided for thruout the entire range, but telephony is available only up to 1,000 meters.

FIGURE 1—Left: Model AT-686, 200 Watt Radio Transmitter. Right: Model AT-702, 1 Kw. Radio Transmitter

For transmitting with interrupted continuous waves, use is made of a motor-driven interrupter mounted within the confines of the transmitter structure. This interrupter functions similarly to the transmitting key on the continuous wave position except that the oscillations are started and stopped at an audio frequency.

The filaments of all tubes are supplied with alternating current, which increases the filament life from 50 to 100 percent

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over the life obtainable by direct current supply. This is because of the fact that when direct current is used, one side of the filament is at higher potential, with respect to the plate, than the other. This condition causes more rapid evaporation of one-half of the filament than the other. When alternating current is used, each half of the filament is alternately at higher and lower potentials with respect to the plates, thereby equalizing the evaporation of the halves of the filament.

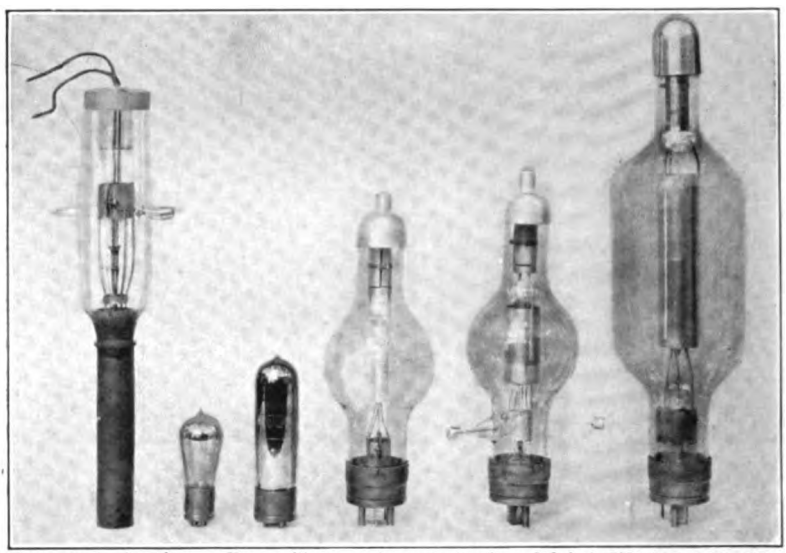

FIGURE 2—Radiotron Power Tubes. Models (Left to Right), UV-207, 202, 203, 204, 206, 208

Negative bias for the grids of the modulator and speech amplifier tubes is obtained by a potentiometer connected across the 125-volt direct current exciter forming one unit of the power equipment. The bias is increased with increase in power.

The wave length of the transmitters is established by the antenna circuit, including the loading inductance and "generating" coil in the transmitter. Series antenna condensers are used to obtain the lower wave lengths.

When the set is installed, adjustments of plate and grid coupling are made for each wave length which the set will utilize. These adjustments, once made, need not be changed thereafter. They cannot be made before installation, because they are dependent on the constants of the antenna on which the set operates.

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All oscillator and all modulator tubes are connected in parallel. The same plate voltage supply is utilized for all tubes in each set, except the 50-watt speech amplifier in the 1,000-watt set. The plate voltage for this tube is 1,000 volts, while that for the remaining 250-watt tubes is 2,000 volts. The 1,000 volts is obtained from one of the 1,000-volt commutators of the power equipment, two of these commutators being connected in series to obtain 2,000 volts.

A small radio choke coil is included in the plate lead of both oscillator and modulator tubes to eliminate parasitic oscillations, which are otherwise likely to be generated when operating tubes in parallel.

The power equipment, illustrated in Figure 3, is a three-unit motor generator set, consisting of a motor, a double current self-excited generator, and a high voltage direct current generator.

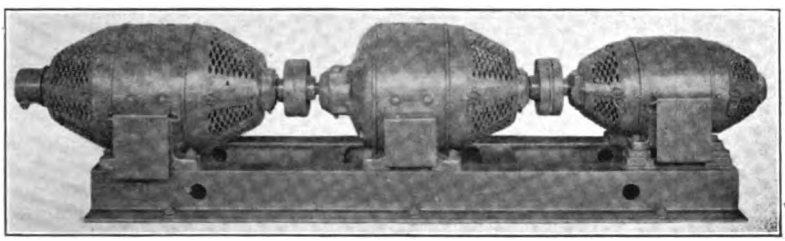

FIGURE 3—2,000-volt D. C. Motor Generator Model UP-703, for Radio Transmitting Equipment, Model ET-3608

The standard equipment consists of either a 115-volt direct current or a 110/220-volt, 50/60-cycle motor. The double current generator provides direct current at 125 volts for the excitation of the high voltage direct current generator, and for the operation of relays and auxiliaries. It also generates single phase alternating current which is stepped down thru suitable transformers for filament supply. The direct current equipments have a speed regulator. It will be noted that the combination of a speed regulator and a self-excited genetator for the high voltage machine makes the filament and plate voltages practically independent of normal variations in supply voltage.

This combination of units in the power equipment also makes the power supply to the transmitter independent of the line supply, that is, the motor may operate from any supply without affecting the output to the transmitter, so long as the speed is maintained.

Suitable protective condensers are mounted on the power

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equipment to absorb high potential surges which are sometimes incidental to the operation of the set.

The motor starter is mounted within the transmitter structure and is operated by means of momentary contact "start" and "stop" push buttons. Momentary contact control has been provided to insure under-voltage and no-voltage protection. In the case of voltage failure, the power equipment will stop and will not start again until the start button is depressed. The use of the momentary contact system also is utilized by the plate overload relay. This relay is made to break the circuit of the holding coil in the starter, shutting down the power equipment in the event of overload in the plate circuit.

The construction of the 1,000-watt transmitter is evident

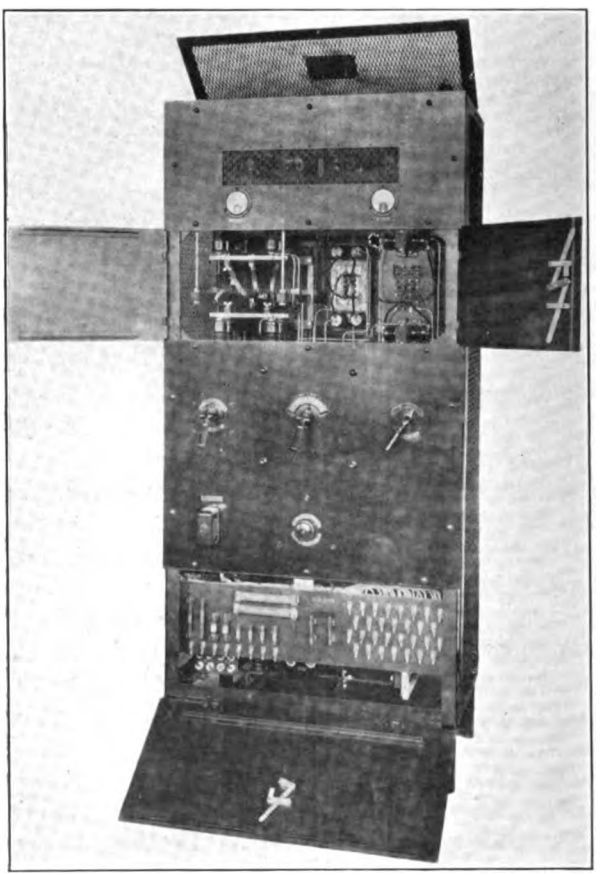

FIGURE 4—1 Kw. Radio Transmitter Model AT-702 for Radio Transmitting Equipment, Model ET-3608

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from Figures 4, 5, and 6. It has been designed with ample consideration for high voltage clearances and creepage distances, ruggedness, and accessibility of component units. On the metal panel forming the front of the unit are mounted the following instruments and controls:

(a) Wave-changing switch.
(b) Signal-change switch.
(c) Power-change switch.
(d) Antenna ammeter.
(e) Plate voltmeter.
(f) Plate circuit relay.
(g) Plate voltage rheostat.

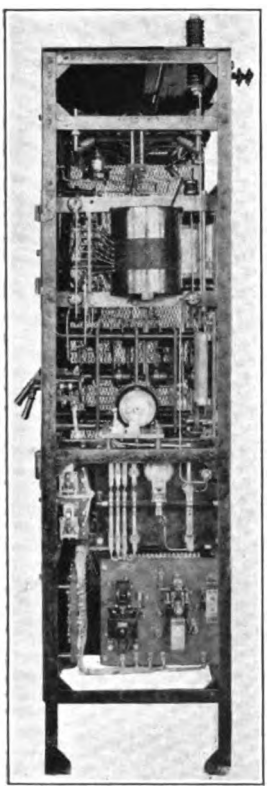

FIGURE 5—1 Kw. Radio Transmitter Model AT-702 for Radio Transmitting Equipment, Model ET-3608

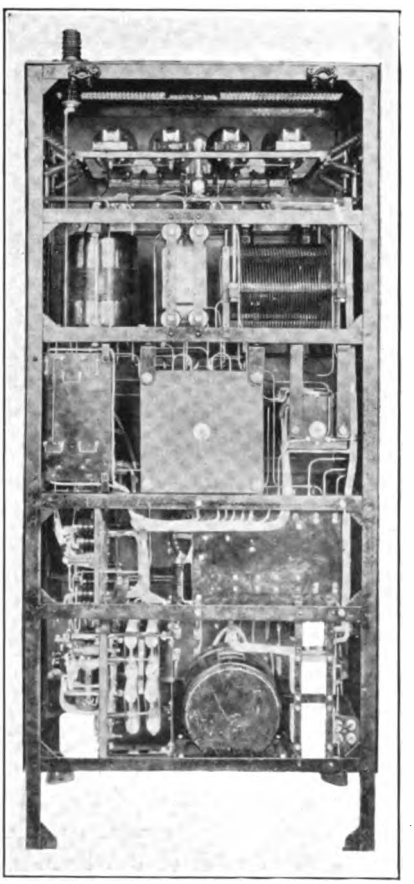

FIGURE 6—1 Kw. Radio Transmitter Model AT-702 for Radio Transmitting Equipment, Model ET-3608

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The over-all dimensions of the transmitter proper are:

Width 29 inches (75.7 cm.).

Depth 23 inches (58.3 cm.), including projection of controls, and so on.

Height 69 inches (1.75 m.), including projection of antenna insulator.

Weight (boxed), approximate 225 lbs. (104 kg.).

The radiotrons are mounted on a spring-suspended rack at the top of the transmitter. They are visible to the operator at all times thru the perforated section of the panel.

The wave-changing switch is one of the most unique units making up the transmitter. It is designed for four positions, making it possible in one operation to shift to any one of the four wave lengths to which the transmitter is adjusted. It is a gang switch, including four banks which control taps on the following circuits and equipment:

(a) Plate coil.
(b) Grid coupling capacity.
(c) Grid coupling connection to the antenna.
(d) Loading inductance and series condensers.

The signal switch has for its function the changing of the connections necessary when transferring from one method of signaling to another. This is accomplished by one operation of the switch, inasmuch as the eight banks composing the switch transfer all circuits affected by the change in signaling.

The power change switch is a two-bank gang switch, simultaneously changing the plate voltage by variation of resistance in the high voltage generator field and changing the biasing voltage on the grids of the modulator tubes. The switch has two positions, for "high" and "low" (approximately one-third) power, respectively. Change in power requires no other adjustment than the operation of this switch.

The loading coil is made of copper strip, wound edgewise with rounded edges. The fact that this coil is wound of bare conductor makes it possible to connect to it at any point for exact tuning to required wave lengths. It is accessible thru a door in the upper part of the transmitter panel. Four bus bars are provided, one for each position of the wave change switch, running the length of the loading inductance. A flexible connector is attached to each bus, and may be shifted along the bus bar until opposite the point at which the other end of the connector will be attached to the loading inductance. This arrange-

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ment eliminates complication in wiring, and insures positive clearance between the four flexible conductors.

Adjustments for plate and grid coupling are also made thru a door in the panel, located in the upper right hand side of the structure.

The three series antenna condensers have capacities of 0.00028, 0.00078, and 0.004 microfarad. These are mounted in the transmitter, and are provided with mica dielectric and aluminum cases.

Provision has been made for remotely operating the send-receive controls from a distant station by a so-called "subscriber." To accomplish this, it is necessary to place one unit at the operator's transmitting station and five units at the subscribers' station. The operator's control unit, shown in Figures 7 and 8

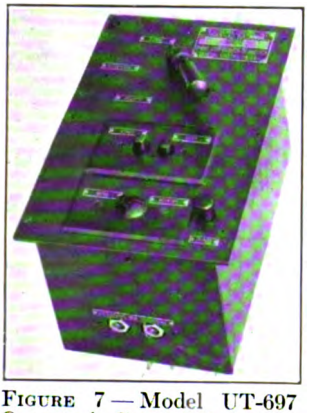

FIGURE 7 — Model UT-697 Operator's Control Unit (Exterior View), for Models ET-3602 and ET-3608 Radio Telephone Transmitters

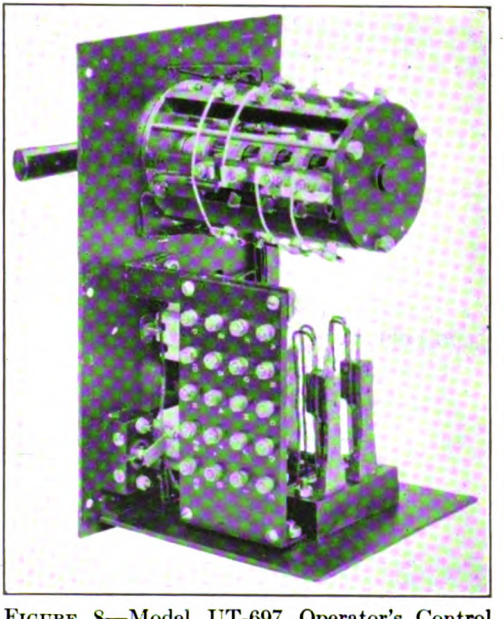

FIGURE 8—Model UT-697 Operator's Control Unit (Interior View) for Models ET-3602 and ET-3608 Radio Telephone Transmitters

is 12 inches (21.8 by 30.2 cm.) long, 8 inches (21.8 cm.) wide and 6 inches (15.1 cm.) deep and weighs approximately 20 lbs. (9.1 kg.). It is designed to be mounted with its top flush with the surface of the operator's table.

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The unit contains the following equipment:

(a) Three-position control switch. This switch has three positions: "Local," "Remote," and "Interphone." When in the "Local" position the operator has complete control of the transmitter. When in the "Remote" position, the send-receive control is transferred to the send-receive switch in the subscriber's control unit. When in the "Interphone" position, wire telephony is available between the operator and the extension station.

(b) Momentary contact "start" and "stop" push buttons. These controls are in the operator's control unit only. It is not possible to start or stop the transmitter from the extension station.

(c) Operator's Send-receive Control. This is a tumbler switch, with name plates to designate its respective positions. When the control is thrown to the "Remote" position, the operator has no control over the send-receive switch.

(d) Ringing Push Button. This button is used to ring the bell at the extension station.

(e) Jack for Breast Microphone.

(f) Jack for Head Phones.

In addition to the control unit the filament voltmeter (Figure 9) is also located on the operator's desk, where it can be readily observed. This is essential in order to obtain the maximum filament life. The operator's accessory apparatus is shown in Figure 10 and the grounding switch in Figure 11.

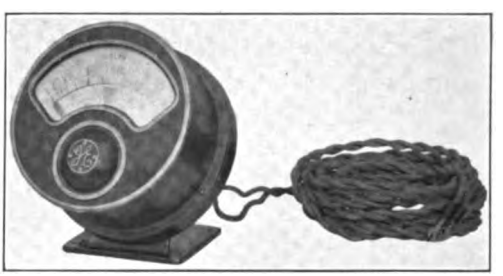

FIGURE 9—Filament Voltmeter with Support

The five additional units at the subscriber's station are shown in Figure 12. The subscriber's unit contains a tumbler send-receive switch which controls the send-receive relay in the transmitter when the operator has thrown the control to the

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subscriber's station, and a "Ringing" push button to call the operator. The unit is approximately 6 inches (15.1 cm.) long and 3 inches (7.6 cm.) high, and 2 inches (5.1 cm.) deep, and is designed for mounting on the desk at the extension station in a convenient position to facilitate the manipulation of the send-receive control.

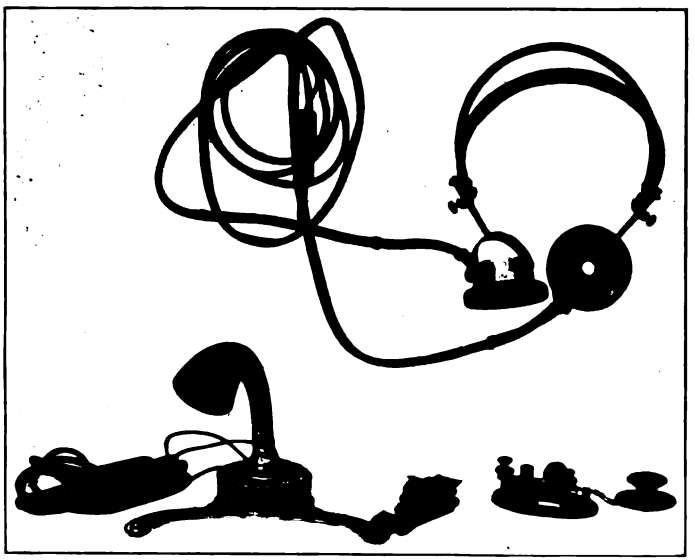

FIGURE 10—Operator's Equipment for Models ET-3602 and ET-3608 Radio Telephone Transmitter

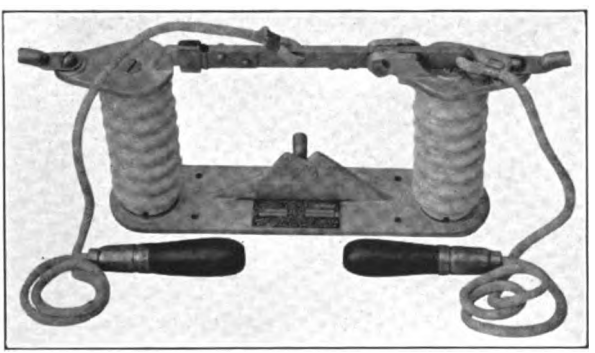

FIGURE 11—Lighting Switch Model UQ-695 used with Radio Transmitting Equipments, Model ET-3608 and ET-3602

In case it is desired to control the transmitter from more than one extension station, the control unit shown in Figure 13 is em-

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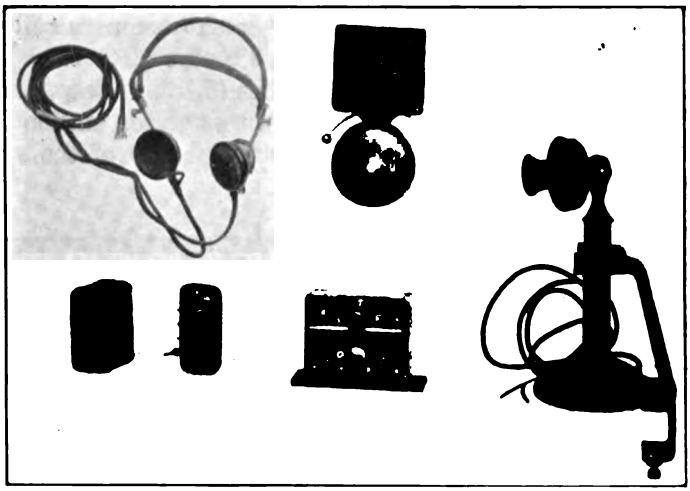

FIGURE 12—Extension Station Equipment for Models ET-3602 and ET-3607 Radio Telephone Transmitters

ployed. This equipment in addition provides communication between the operator and any one of five extension stations.

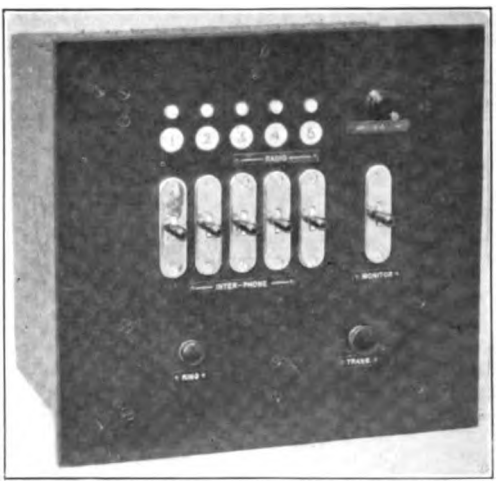

FIGURE 13—Control Unit for Multiple Extension System

Spare parts for either the ET-3602 or ET-3608 equipment are supplied in a suitable box illustrated in Figure 14.

Circuit diagrams for the ET-3608 transmitter are shown in Figures 15 and 16 and are self-explanatory. The circuits of the

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ET-3602 equipment are essentially the same. Attention is called to the use of the exciter voltage for biasing the oscillator grids for keying purposes.

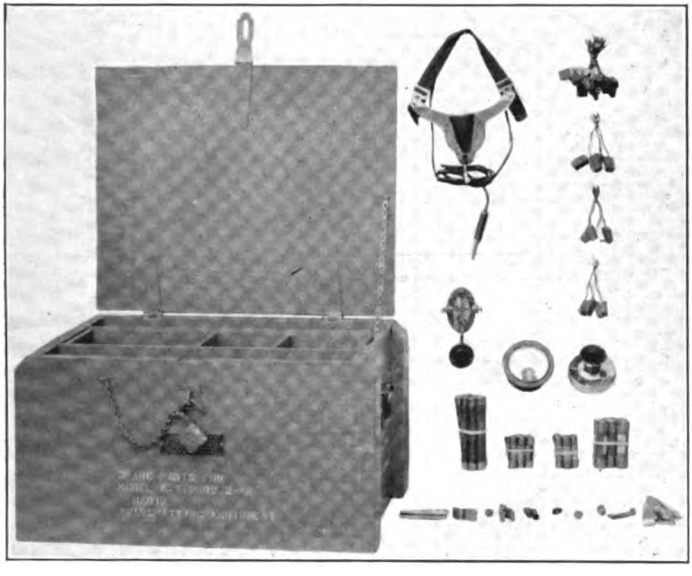

FIGURE 14—Spare Part Box Model for ET-3602, 200 Watt Radio Transmitting Equipment

The linear relation between the plate potential of the oscillators and the antenna current which is essential for telephony is illustrated in Figure 17. The variation of antenna current with filament volts is shown in Figure 18. Typical operating characteristics for the UV-203 and UV-204 radiotrons are shown in Figures 19 and 20.

Figure 19-B shows the plate and grid current voltage characteristics for a type UV-203 radiotron. These characteristics are of value in predicting the performance of the radiotron, as they cover the range of grid and plate voltages during which plate current flows when the associated circuit is adjusted for efficient operation. It will be seen that plate current flows only when the grid is positive, or only very slightly negative, so that the flow of plate current is necessarily limited to a fraction of a cycle, usually less than one-half.

By use of this characteristic, and assuming different angles during which plate current flows in the circuit, the performance of the tube under a number of conditions may be predicted and

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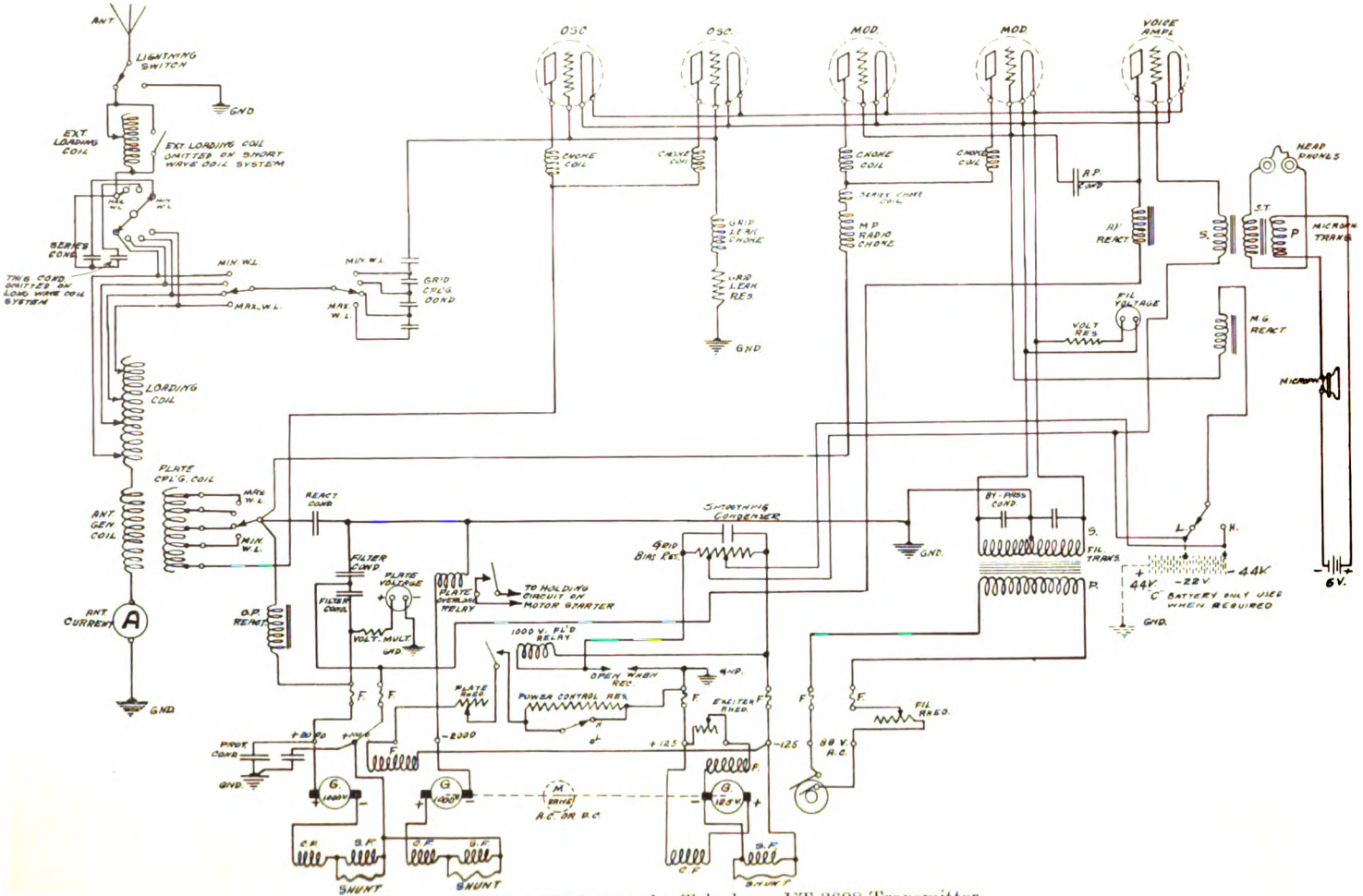

FIGURE 15—Circuit Diagram for Telephony ET-3608 Transmitter

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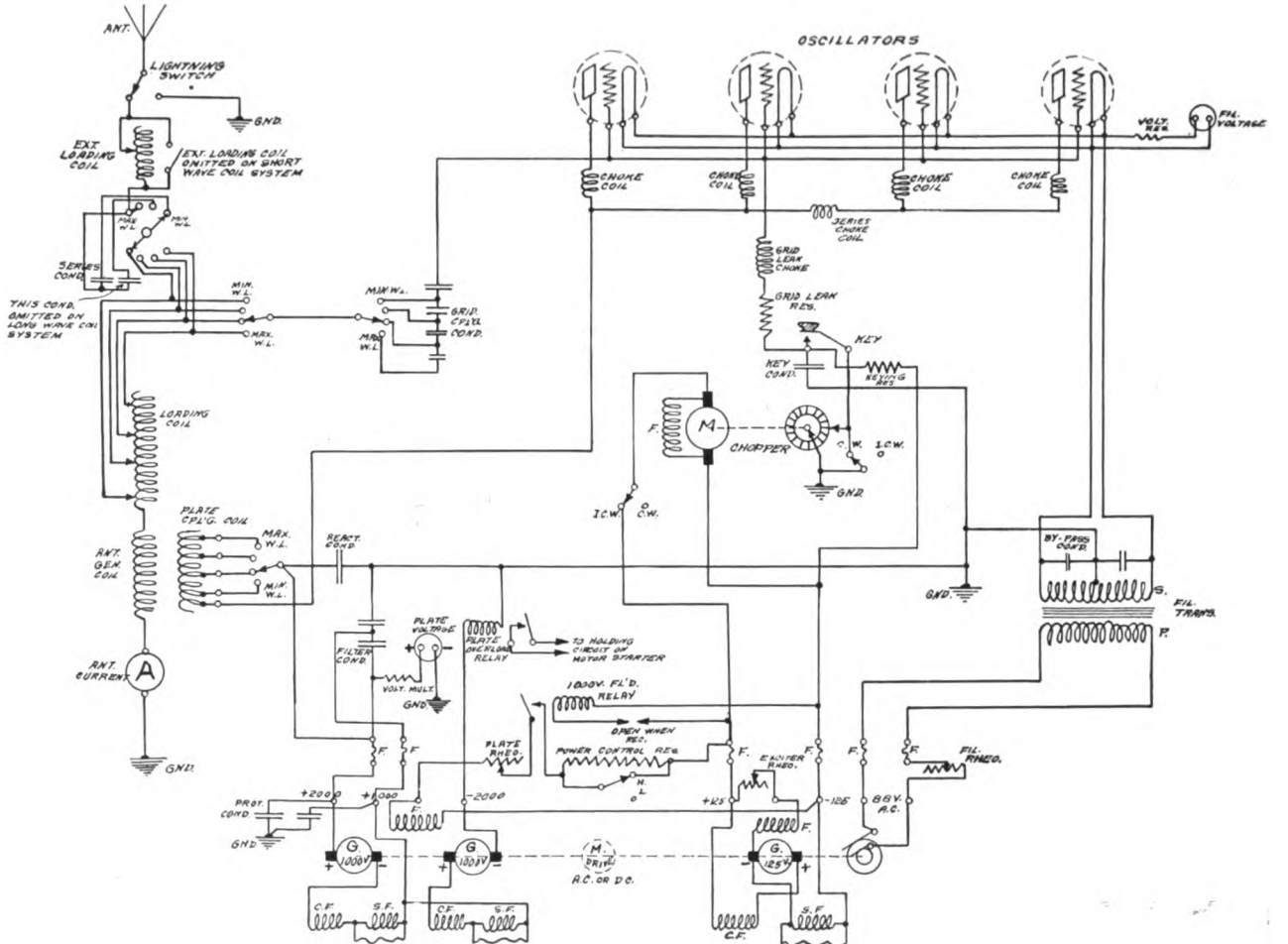

FIGURE 16—Circuit Diagram for Telegraphy, ET-3608 Transmitter

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the conditions for best performance for any given output may be determined. This has been done, and the results are shown in Figure 19-A. The use of a constant plate voltage of 1,000 volts is assumed here. It will be seen that for low outputs, the minimum instantaneous plate voltage is low, and the direct current grid voltage is high, the alternating current grid voltage being

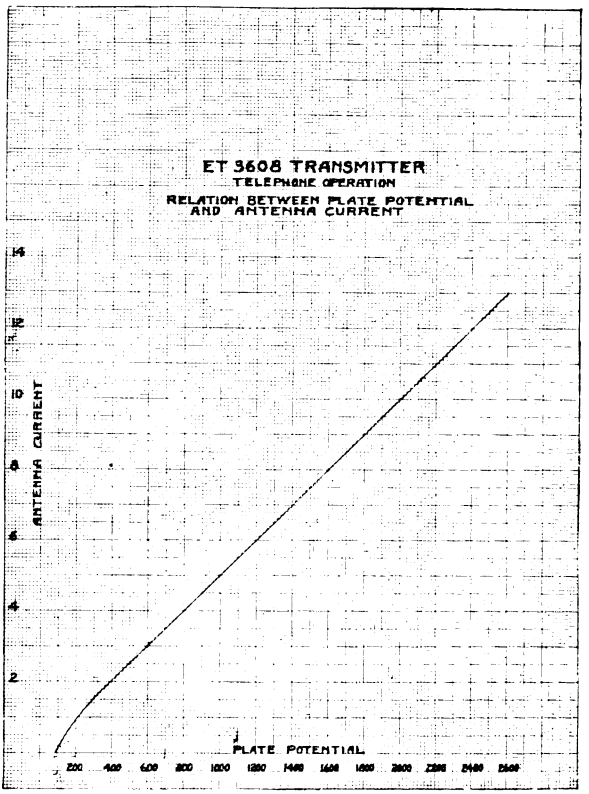

FIGURE 17—ET-3608 Transmitter Telephone Operation. Relation Between Plate Potential and Antenna Current

nearly constant over a considerable range of outputs. This means that the grid voltage does not reach a high positive value, and while it is positive, the plate voltage is low. Inspection of Figure 19-B shows that instantaneous values of plate current, and hence of tube input are low under these conditions, which would be expected for low output at high efficiency. As the output is increased, the grid becomes more positive and remains so for a longer portion of the cycle, hence the integrated grid current

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becomes greater, and this, with the requirement of lower direct current grid volts, results in the use of a low grid leak resistance.

Figure 19-C shows the efficiency of the tube at different outputs when working with the best circuit adjustments. The electron loss is also shown, the loss in the grid leak being negligible.

It is interesting to note that while the tube is rated at 50 watts output with 100 watts electron loss, it is actually capable of delivering 124 watts to the circuit with an electron loss of 100 watts. To realize this output requires careful adjustment of the circuit and special care that the grid and plate voltages should be 180 degrees out of phase, as dephasing of the grid voltage increases the tube loss considerably. It should also be remembered that the output of the tube is the total power delivered to the circuit, and if the circuit has considerable loss, the power available may be much less than the output of the tube.

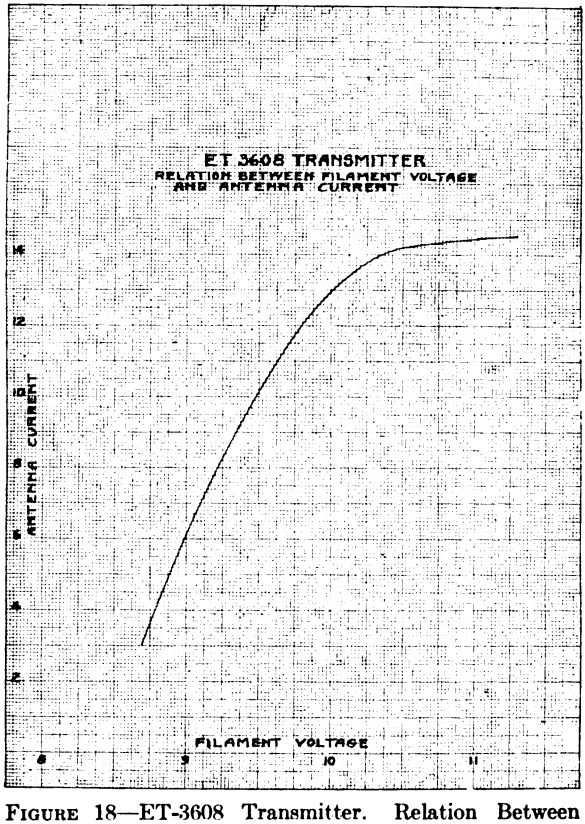

FIGURE 18—ET-3608 Transmitter. Relation Between Filament Voltage and Antenna Current

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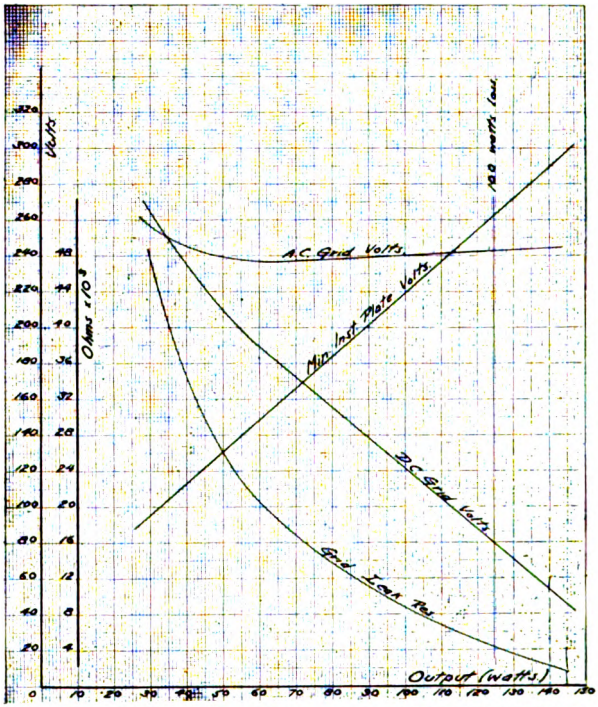

FIGURE 19A—Operating Characteristics of Typical UV-203 Radiotron

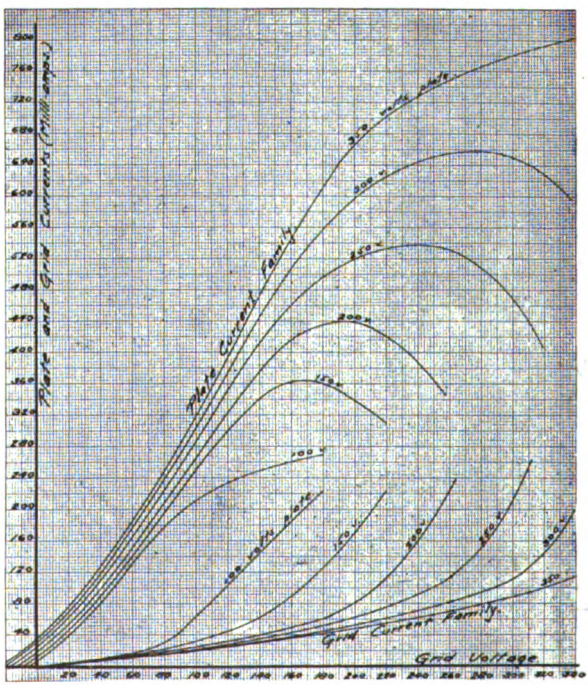

FIGURE 19B—Operating Characteristics of Typical UV-203 Radiotron

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The receiving equipment used with the ET-3608 and ET-3602 transmitter is shown in Figure 21. The tuner consists of the usual two-circuit type utilizing regeneration. A wave length range of from 300 to 3,000 meters is provided. The amplifier system comprises standard detector and two-stage audio amplifier units. The UV-200 radiotron is used as a detector and the UV-201 (Figure 22) for the audio amplifier stages.

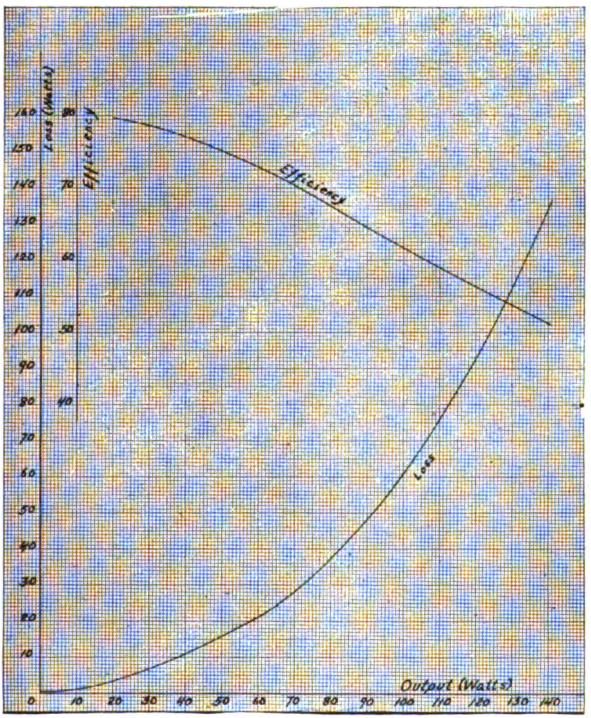

FIGURE 19C—Operating Characteristics of UV-203, Radiotron at 1,000 Volts D. C.

SPARK TUBE TRANSMITTER

The commercial tube transmitters just described were designed to replace completely the present spark equipment. In order to permit reception of these transmitters utilizing receivers designed only for spark transmitter work, means for interrupted continuous wave telegraphy were included in the tube sets. It is obvious that in some cases such an abrupt change in transmitting equipments could not be economically justified. The need for providing the advantages of continuous wave transmission

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and yet retaining the spark equipment resulted in the design of an attachment which would permit either spark or continuous wave telegraphy.

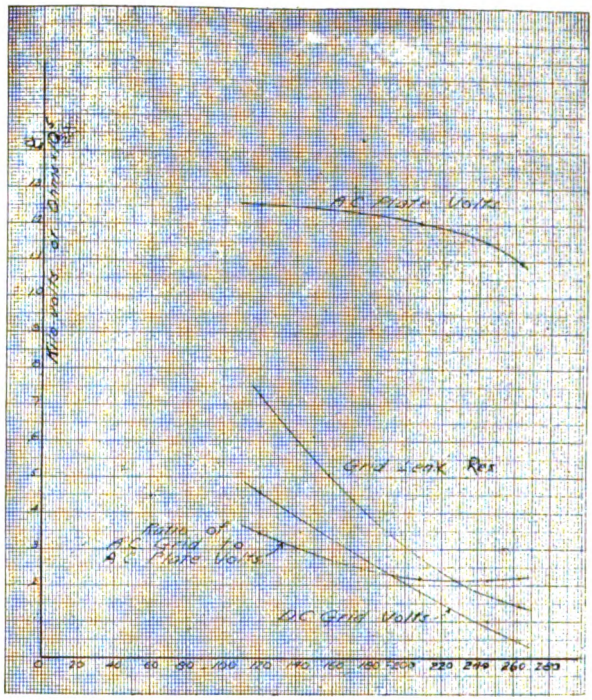
A.C. Plate Volts
Grid Leak Res.
Ratio of A.C. Grid to A.C. Plate Volts
D.C. Grid Volts
0 20 40 60 80 100 120 140 160 180 200 220 240 260 280

FIGURE 20A—Operating Characteristics of Typical UV-204 Radiotron

The tube attachment provides continuous wave telegraphy on any two wave lengths in the band of 1,800 to 2,600 meters. The output is approximately 750 watts. The tube equipment consists of one UV-218 kenotron operating as a half wave rectifier and a UV-206 radiotron as an oscillator. The entire power supply is furnished by the 500-cycle generator normally used with the spark transmitter. A filter is provided to reduce the ripple in the rectifier output to about 5 percent.

The general construction is shown in Figures 23 and 24. A double-throw switch not shown in these figures permits changing from spark to continuous wave transmission. The switch shown in Figure 24 provides selection of either of the wave lengths for which the equipment has been adjusted. As in the case of the ET-3608 transmitters, a filament voltmeter is located on the operator's table. The circuit for this unit is shown in Figure 25.

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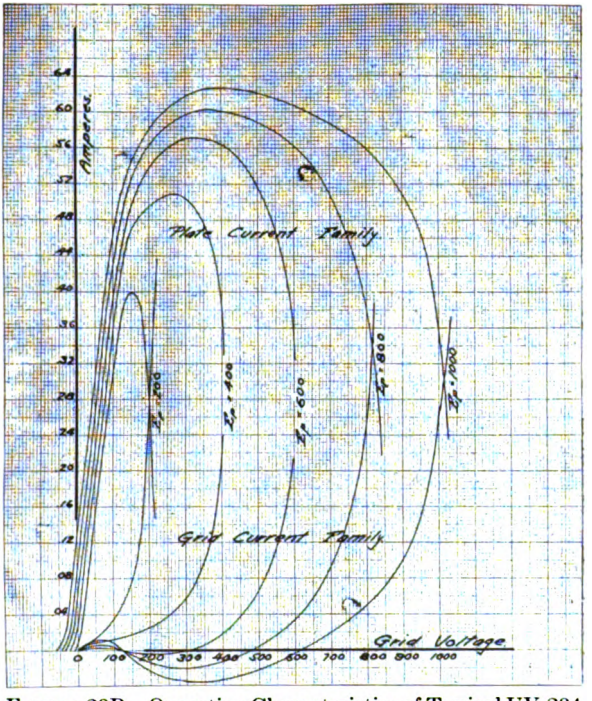

FIGURE 20B—Operating Characteristics of Typical UV-204 Radiotron

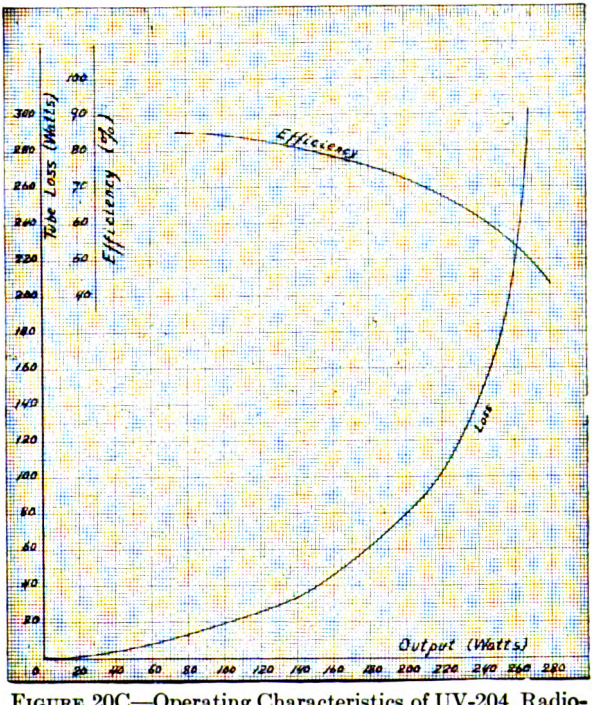

FIGURE 20C—Operating Characteristics of UV-204, Radiotron at 2,000 Volts D. C.

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Duplex Transmitting Equipment

The general operation of this type of equipment has been fully considered in a recent issue of the Proceedings. The particular set manufactured by the General Electric Company is shown in Figures 26 and 27. The rectifier utilizes two UV-218 kenotrons operating in a single phase, full wave circuit. All power is supplied by a 500-cycle generator quite similar to that ordinarily supplied for spark equipments.

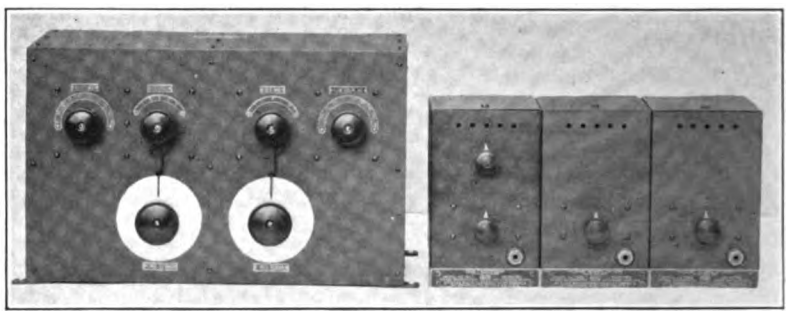

Figure 21—Radio Tuned Coupler Model AR-1529, Detector Model AD-1527, and 2 Tone Amplifiers Model AD-1528, Front View

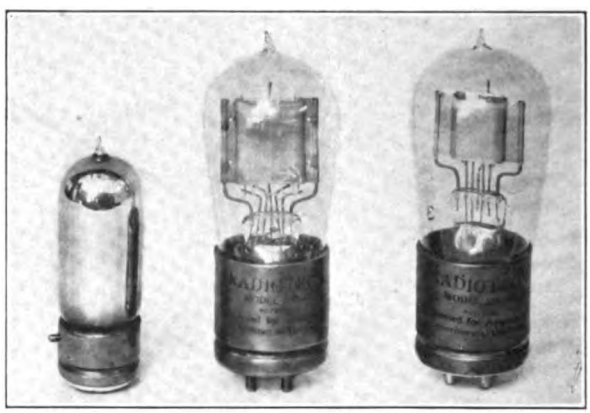

Figure 22—Radiotrons, Models UV-199, UV-200, UV-201

The transmitter unit covers a wave length range of 300 to 800 meters. Two UV-206 radiotrons are used, one as an oscillator, the other as a modulator. The speech amplifier consists of a UV-203 tube.

The receiver illustrated in Figure 28 provides reception over a range of wave lengths from 250 to 4,000 meters and uses 8

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UV-201 radiotrons. Circuit diagrams are shown in Figures 29 and 30. This particular equipment was used on the S. S. America during the tests made in 1922.

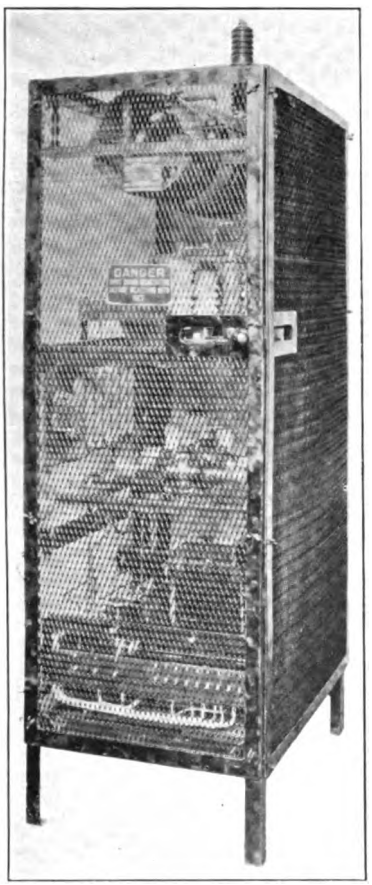

FIGURE 23—Vacuum Tube Radio Transmitting Equipment for use in Connection with Spark Sets

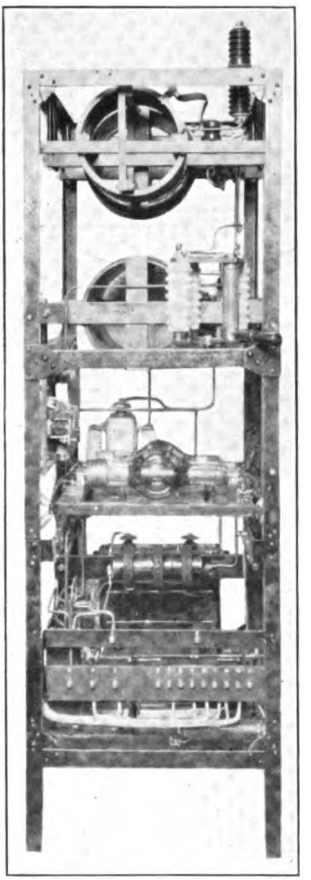

FIGURE 24—Vacuum Tube Radio Transmitting Equipment for Use in Connection with Spark Sets

MODEL ET-3619 TRANSMITTER

This equipment was designed for service on yachts or small vessels where only relatively short distance transmission is required. Ordinarily provision is made for only continuous wave telegraphy and telephony. Interrupted continuous wave telegraphy can, however, be obtained by the addition of a motor-driven interrupter. For telegraphy, four UV-202 radiotrons

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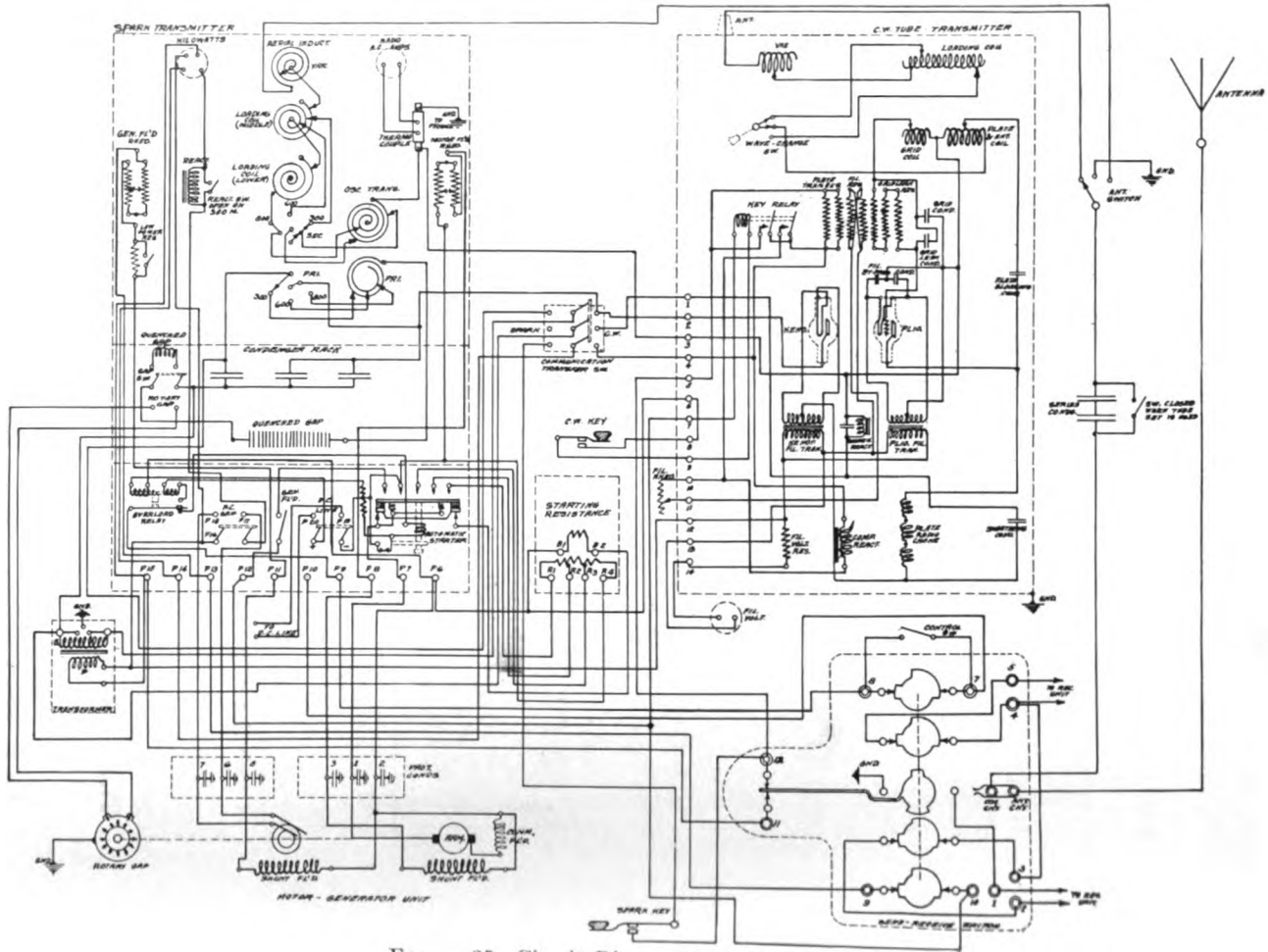

FIGURE 25—Circuit Diagram for Spark-Tube Set

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(5 watts) are employed as oscillators. For telephony, two of these tubes are utilized as modulators.

A front view of the transmitter unit is shown in Figure 31. Two controls are supplied on the panel, one a signal switch which changes the connections from telephony to telegraphy, and the other an antenna condenser for wave length adjustment. Adjustment of the oscillating system is provided by connectors on the coil shown in the rear view of the transmitter unit (Figure 32). This view illustrates the method of mounting the various standardized units, the general plan of wiring, and the terminal board located at the base of the unit. The antenna insulator is shown at the lower left-hand side.

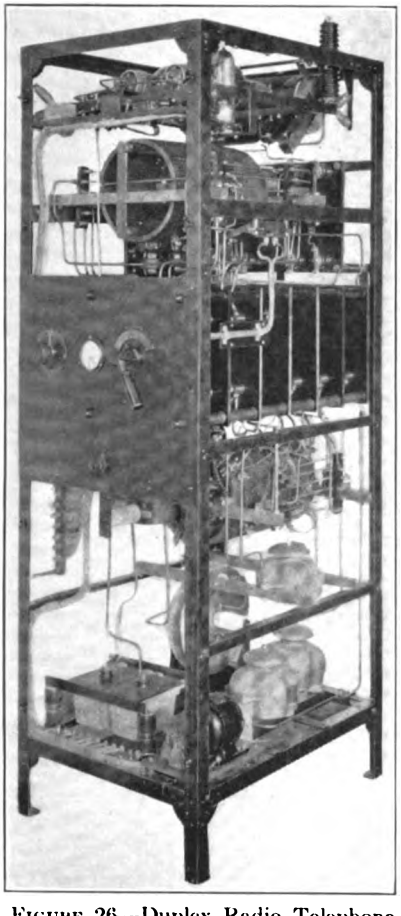

FIGURE 26—Duplex Radio Telephone Transmitter; Radio Unit

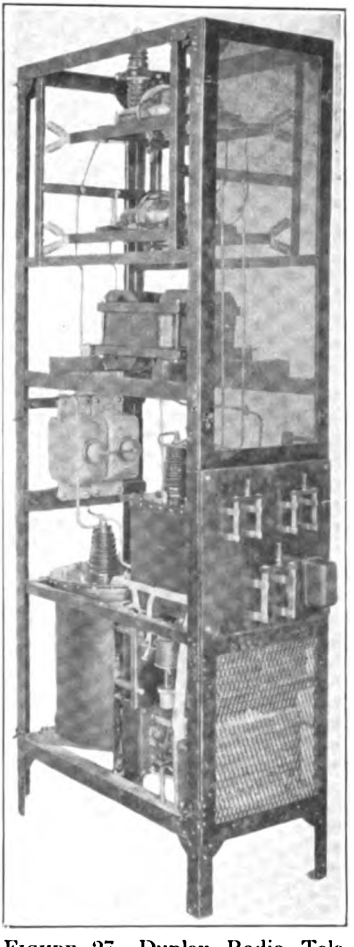

FIGURE 27—Duplex Radio Telephone Transmitter; Rectifier Unit

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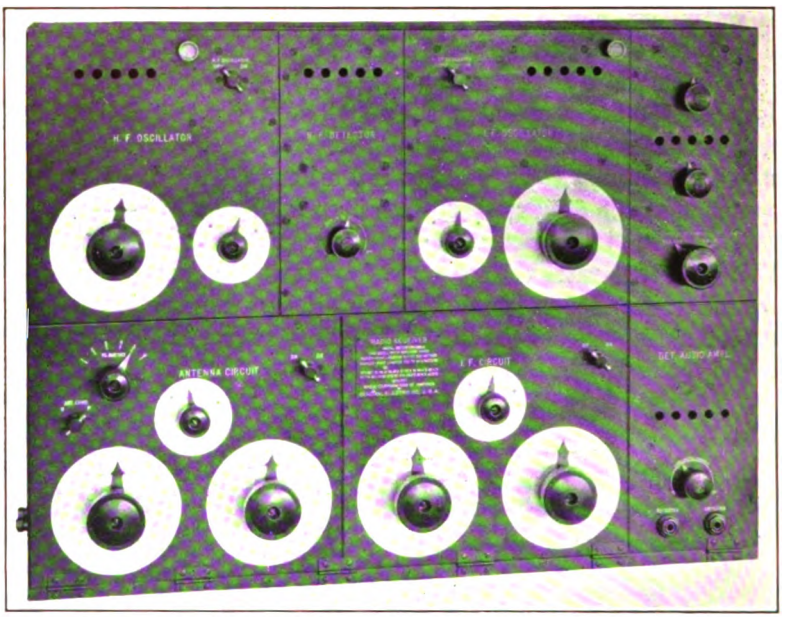

FIGURE 28—Model of Radio Receiver for Duplex Operation.

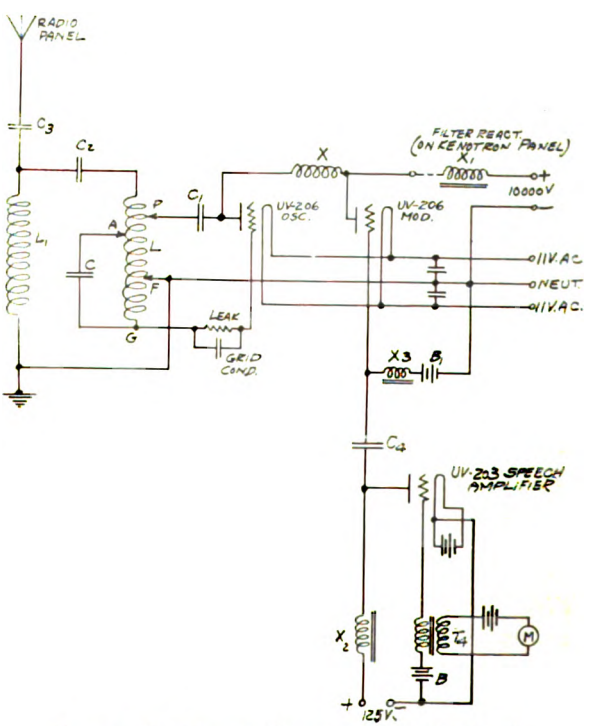

FIGURE 29—Circuit Diagram of Radio Panel

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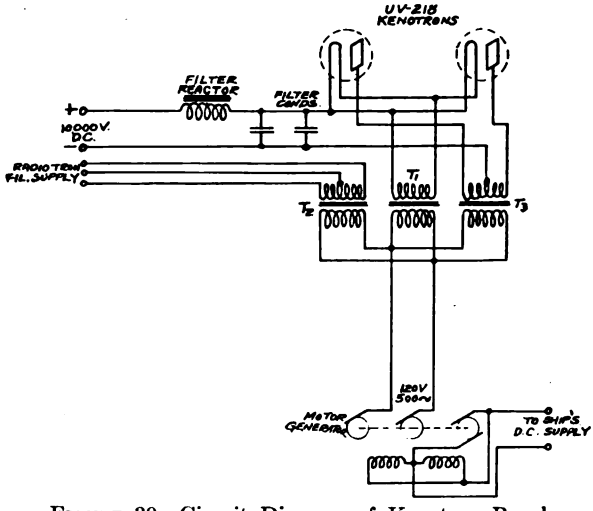

FIGURE 30—Circuit Diagram of Kenotron Panel

FIGURE 31—Model ET-3620, Kenotron Rectifier and Model ET-3619, Radio Transmitter (Front)

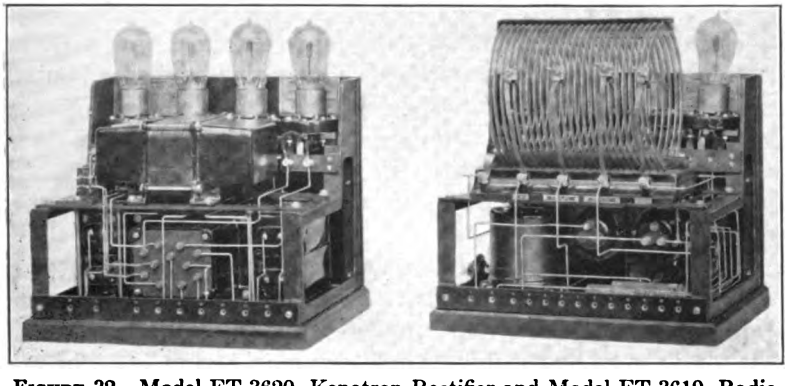

FIGURE 32—Model ET-3620, Kenotron Rectifier and Model ET-3619, Radio Transmitter (Back)

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A schematic circuit diagram is shown in Figure 33. Operating characteristics of the UV-202 radiotron are indicated in Figure 34.

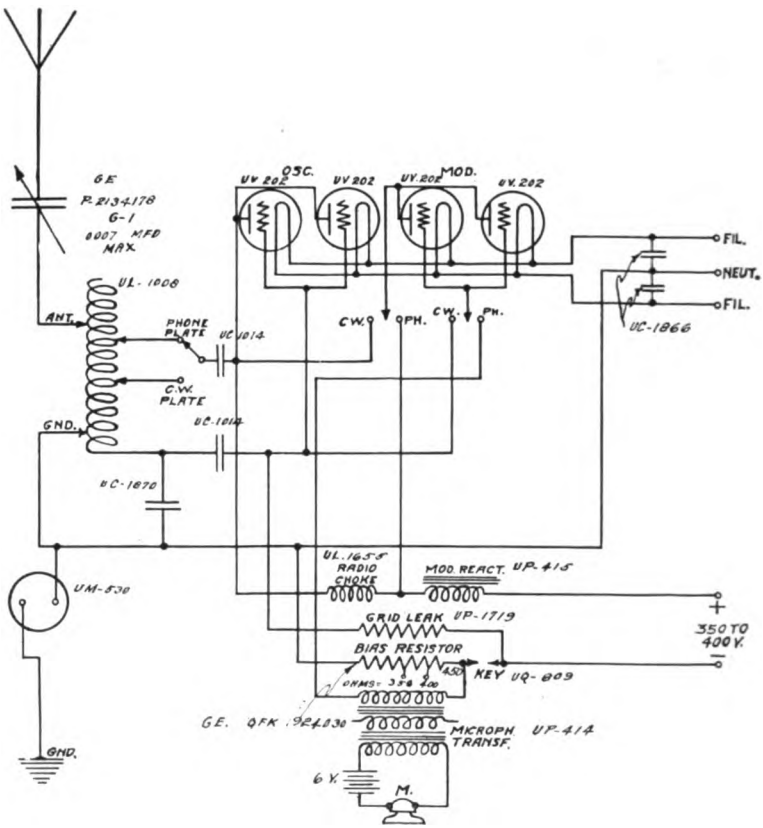

FIGURE 33—Circuit Diagram ET-3619, Transmitter

Power for the transmitter unit may be obtained from a motor generator or a kenotron rectifier. The motor generator is used principally where only direct current is available. In this case the high voltage direct current supply for the plate circuits is obtained from the generator. The filament energy is furnished by a transformer, the primary of which is supplied from slip rings on the motor.

The circuit arrangement shown in Figure 35 constitutes a single phase full wave rectifier. If no filter or smoothing network were used, the current supplied to the oscillator would have the form shown by the middle oscillogram in Figure 36. The use of the filter reduces the ripple so that the output of the rectifier

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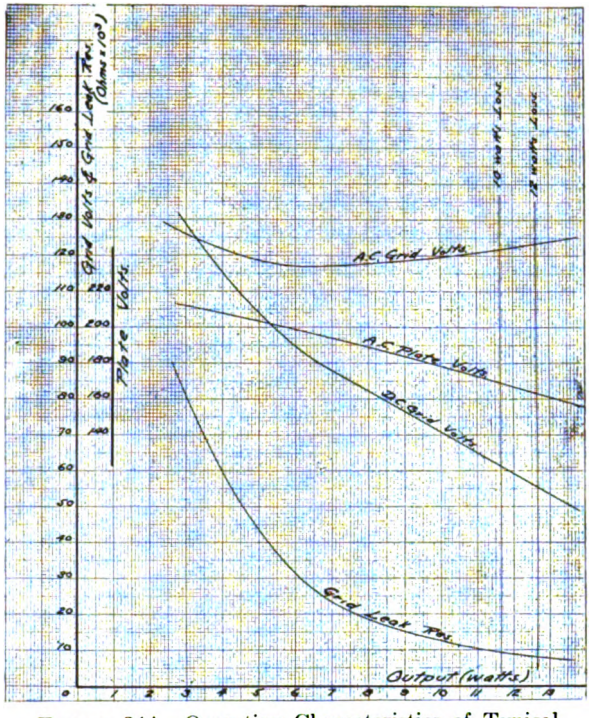

FIGURE 34A—Operating Characteristics of Typical UV-202

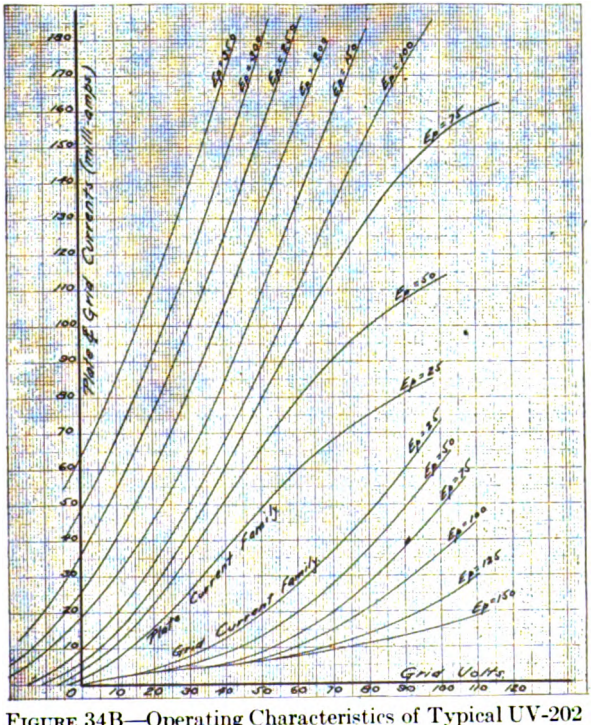

FIGURE 34B—Operating Characteristics of Typical UV-202

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takes the form shown in Figure 37. The UP-1368 transformer has three secondary windings, two of which supply power to the filaments of the UV-216 kenotrons, and the UV-202 radiotrons (Figure 38). The third winding terminates on the plates of the kenotrons. The taps on primary of the transformer permit the

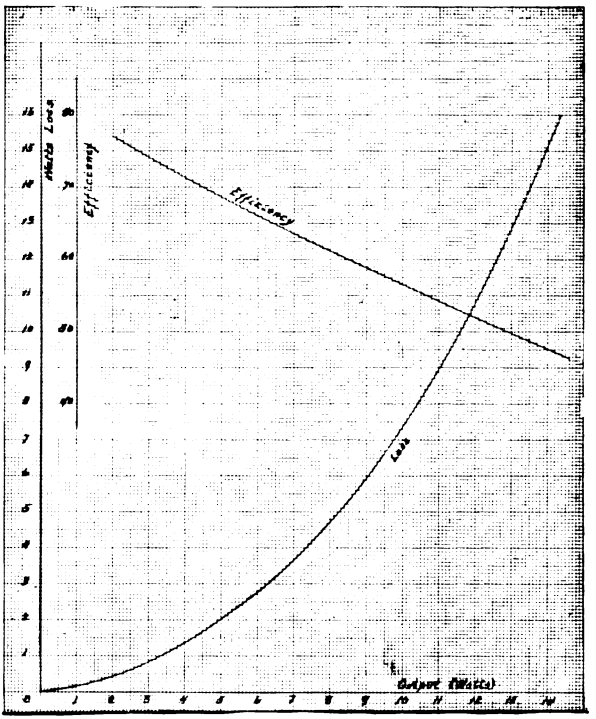

FIGURE 34C—Operating Characteristics of UV-202, Pliotron at 350 Volts D. C.

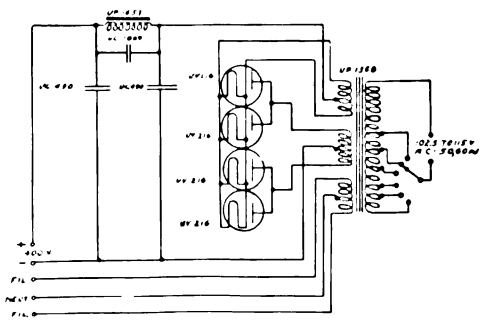

FIGURE 35—Circuit Diagram of Model ET-3620, Kenotron Rectifier

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proper secondary voltages over a range of line voltages from 102.5 to 115.

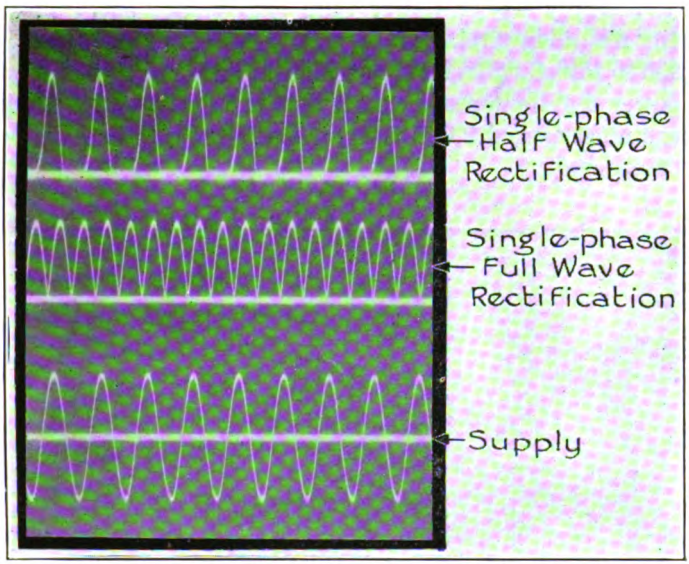

FIGURE 36

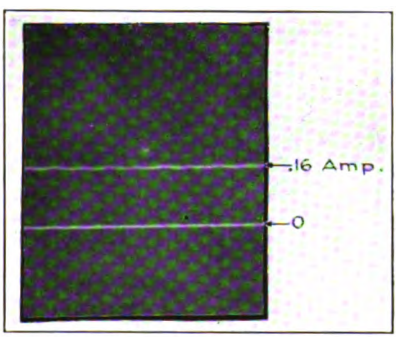

FIGURE 37—Current Wave ET-3620, Kenotron Rectifier

The load characteristics of the ET-3620 are shown in Figure 39. These characteristics were obtained by operating the rectifier under various load conditions, but holding the filament load constant. The over-all efficiency is based on the ratio of kenotron output plus filament losses to the total primary input. The actual over-all efficiency of low power rectifiers is not high, because of the filament energy. A characteristic curve of the UV-216 kenotron is shown in Figure 40.

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Rectifiers

In view of the service requirements a fixed station is usually of considerably higher power than ship equipment. This ordinarily results in a relatively high voltage direct current supply (10,000 to 15,000 volts) for the oscillator plates. At present, when the power requirements are such that the direct current supply voltage must exceed 2,000 volts, it is desirable to employ kenotron rectifiers.

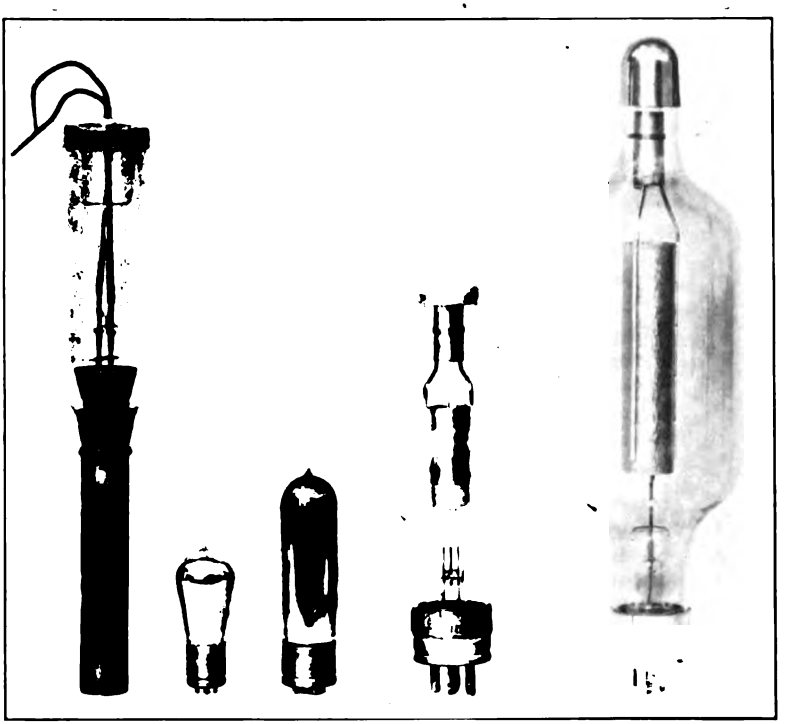

Figure 38—Kenotrons: Models (Left to Right), 214, 216, 217, 218, 219

Rectifiers may be single or polyphase, depending largely on the nature of the power supply and the value of rectified current required. The chief advantage of polyphase over single phase rectification lies in the lower value and higher frequency of the alternating current components in the rectified voltage wave, thereby making it easier to smoothe. Single phase rectification is commonly employed where only a small value of rectified power is desired, such that the tube capacity required for polyphase rectification is in excess of the required output.

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The simplest rectifier is one which utilizes only one-half of the alternating current voltage wave. The half wave rectifier has the advantage of employing fewer rectifier tubes, the minimum number being equal to the number of phases, but the full wave rectifier, rectifying both halves of the voltage wave, possesses such advantages over the half wave rectifier that the latter is little used, except in cases where the power demand is very small, or where extreme simplicity or low first cost of apparatus are desired.

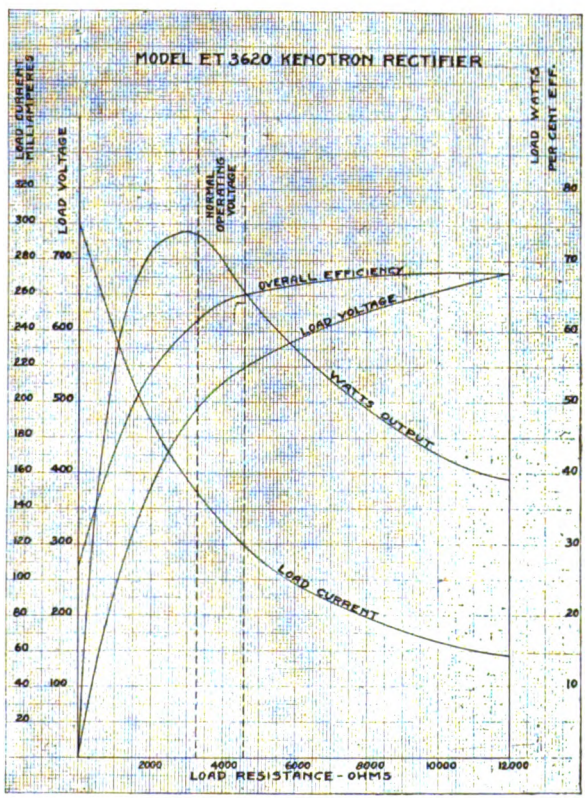

FIGURE 39

In general, full wave rectifiers are preferable to half-wave rectifiers for the following reasons:

(1) The full wave rectifier delivers a smoother voltage wave.

(2) The half wave rectifier operates the step-up transformer with a direct current component of flux in the core, with correspondingly high iron losses.

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(3) The step-up transformer in a half wave rectifier draws an unsymmetrical current from the line, with large, even-harmonic components. The accompanying poor regulation is usually objectionable.

(4) In the case of a polyphase rectifier, the resultant even-harmonic voltages set up in the line have a phase rotation opposite to that of the fundamental. This is highly objectionable in the case of rotating machinery operating on the line.

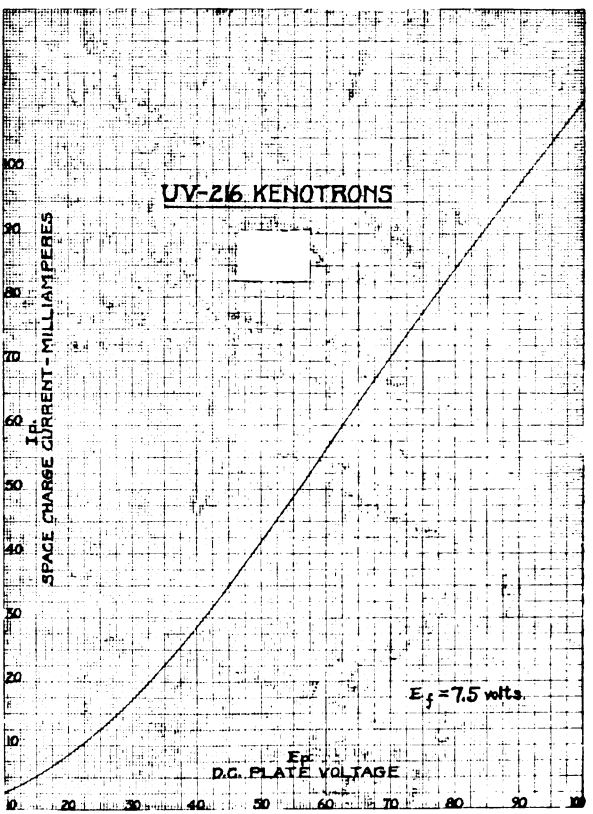

FIGURE 40

SINGLE PHASE HALF AND FULL WAVE RECTIFIERS

Figure 41 shows the circuit connections and resultant voltages for both half and full wave rectification on a single phase system.

THREE PHASE HALF WAVE RECTIFIER

Figure 42 shows a three phase half wave rectifier connection.

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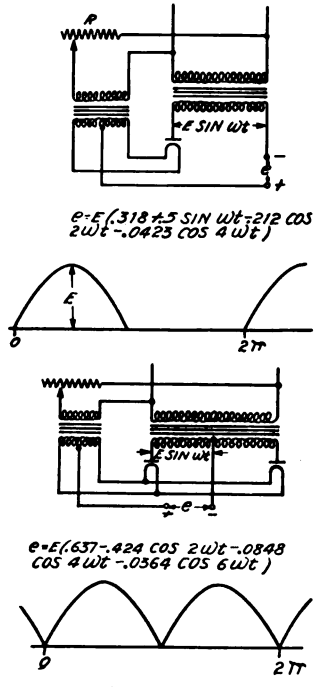

FIGURE 41

The dotted lines represent the transformer voltage waves. The current waves follow the rectifier voltage wave, assuming negligible resistance and reactance in the rectifier. The reason for this lies in the valve action of the kenotron, whereby, at any instant, only the kenotron with the highest positive potential on its plate will pass current. Thus each tube passes current for one-third of a cycle. The primary current in the transformer is unsymmetrical, and in the limiting case of high reactance in the load, assumes the square wave shape shown in the figure. This wave, if analyzed, is found to have a second harmonic component with a magnitude of 50 percent of the fundamental and a fourth harmonic with a magnitude of 25 percent of the fundamental, besides other higher even harmonics of lesser magnitude.

It will be noted that the filaments are heated from a three phase circuit. This is done so that the filament and space charge currents will add up equally in all kenotrons and produce equal filament temperatures. If all the filaments are lighted from one phase, the phase angle between filament and space charge current will differ from 120 degrees in successive tubes, and the sums will not be equal. The resultant unequal filament temperatures

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shorten the mean filament life. Another method of securing equal filament temperatures is to heat the filaments from a single phase source, not synchronous with a three phase source.

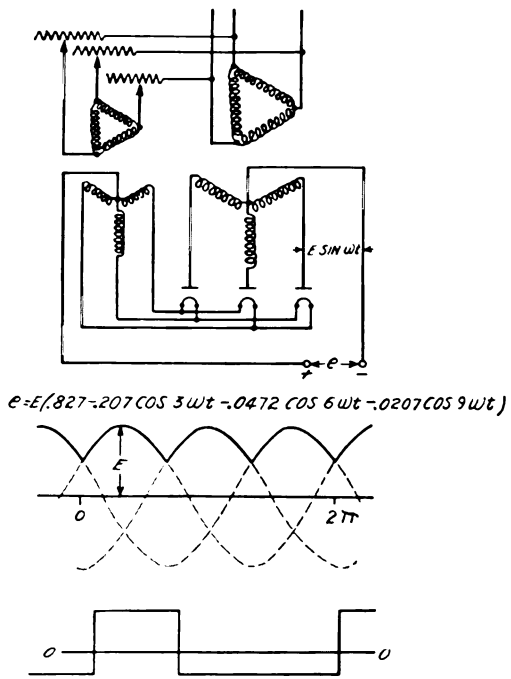

FIGURE 42

THREE PHASE FULL WAVE RECTIFIER

Figure 43 shows a three phase full wave rectifier. The step-up transformer for such a rectifier is wound with mid-taps on each of the three phases, and these are joined together to form the negative terminal of the rectifier. It will be noted that the currents drawn from the two sections of each secondary winding are equal and opposite in sign, hence the primary current is symmetrical and contains no even harmonics.

Since each tube passes current only when the voltage on its plate has a higher positive value than any other plate, it follows that in the three phase half wave rectifier, each tube passes current for one-third of the cycle, while in the three phase full wave rectifier, each tube passes current for only one-sixth of a cycle. Thus it follows that three phase half wave rectification is preferable to full wave rectification in that it utilizes the filament

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emission to a much greater extent. On the other hand, full wave rectification is more desirable on account of its better regulation, absence of even harmonic in the line, and smaller harmonic components in the rectified voltage wave.

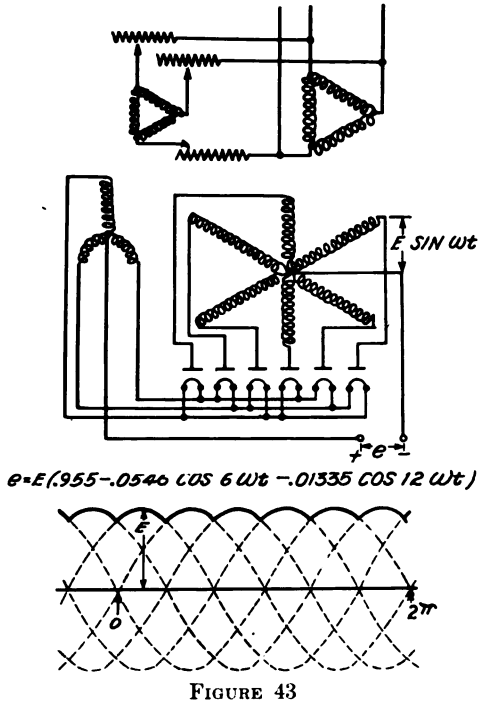

FIGURE 43

THREE PHASE DOUBLE Y RECTIFIER

The advantages of both full wave and half wave polyphase rectifiers may be realized by connecting the high tension windings of the transformer to form two Y's, 180 degrees out of phase, as shown in Figure 44; each Y, with its kenotrons, is a half wave rectifier delivering voltage waves, E_1 and E_2, with the odd multiples of the triple harmonic components in the two Y's, 180 degrees out of phase and the even components in phase. If we connect the neutral points of the two Y's thru a large reactance, and draw current from the rectifier thru the mid-point of the reactance, the odd multiples of the triple harmonic component will not appear in the rectified voltage wave, since their value is zero at this point, but the even harmonic components will appear. The voltage across the reactor, or interphase transformer is the sum of the absolute values of the odd multiples of

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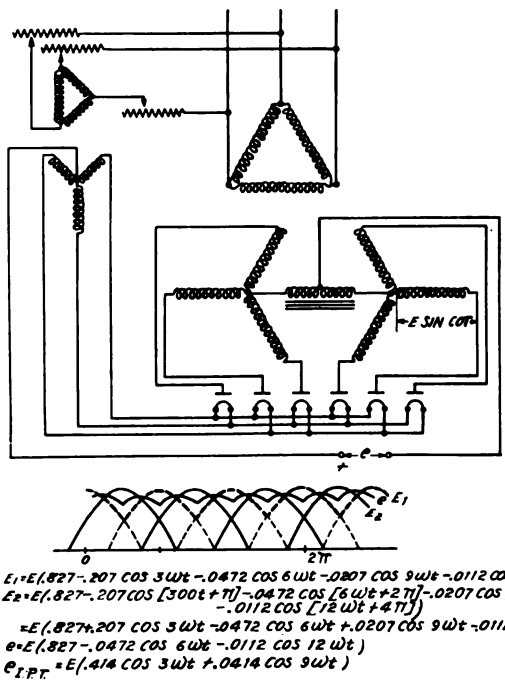
the triple harmonic frequency voltage due to each Y. The current caused by this voltage is the interphase transformer magnetizing current, and circulates thru the kenotrons and transformer windings without appearing in the load.



$E_1 = E(.827 - .207 \cos 3\omega t - .0472 \cos 6\omega t - .0807 \cos 9\omega t - .0112 \cos 12\omega t)$

$E_2 = E(.827 - .207 \cos [300t + \pi] - .0472 \cos [6\omega t + 2\pi] - .0207 \cos [9\omega t + 3\pi] - .0112 \cos [12\omega t + 4\pi])$

$= E(.827 + .207 \cos 3\omega t - .0472 \cos 6\omega t + .0207 \cos 9\omega t - .0112 \cos 12\omega t)$

$e = E(.827 - .0472 \cos 6\omega t - .0112 \cos 12\omega t)$

$e_{I.P.T.} = E(.414 \cos 3\omega t + .0414 \cos 9\omega t)$

FIGURE 44

The current waves thru each kenotron are nearly square, lasting for one-third of the cycle. Since there are two high tension windings for each phase passing current in opposite directions, the primary current wave is symmetrical and contains no even harmonics. The direct current component delivered by each of the two Y's is one-half of the total direct current, so that each tube is required to pass only one-half the maximum value of current required per tube in an ordinary three phase full wave rectifier. This means that the filament temperature may be lower since less emission is required, and the filament life is accordingly prolonged.

Figures 45 and 46 show typical rectifier assemblies and Figure 38 illustrates the standardized kenotrons used in the various rectifiers. Characteristic curves of the UV-214, 218, and 219 are shown in Figures 47, 48, and 49.

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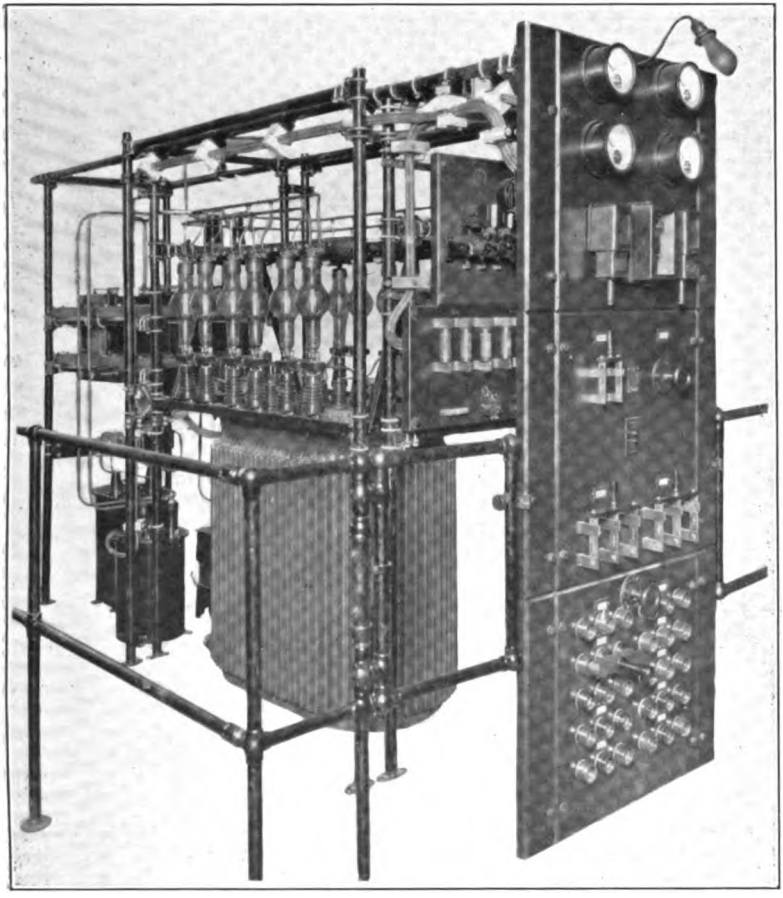

FIGURE 45—30 Kw. Rectifier Unit

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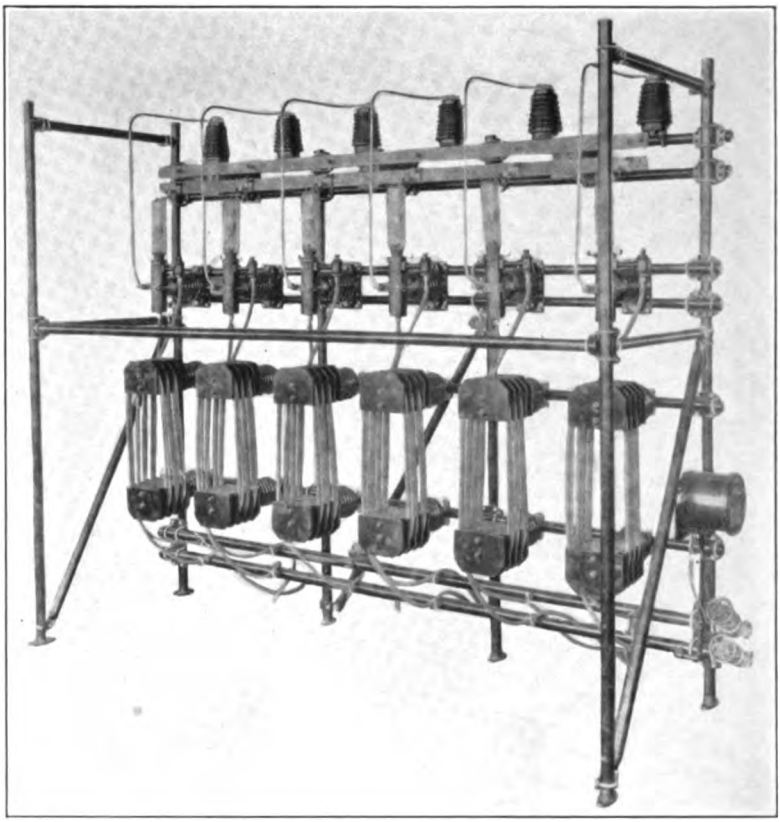

FIGURE 46—Assembly of UV-214, Kenotrons

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Two Kilowatt Fixed Station Equipment

Figures 50 and 51 illustrate one type of fixed station equipment. The factors to be noted are the ruggedness, simplicity, and freedom from congestion of both the units and the wiring. The resemblance to a power switchboard is quite striking and results from the use of a great number of standard units normally utilized in power practice.

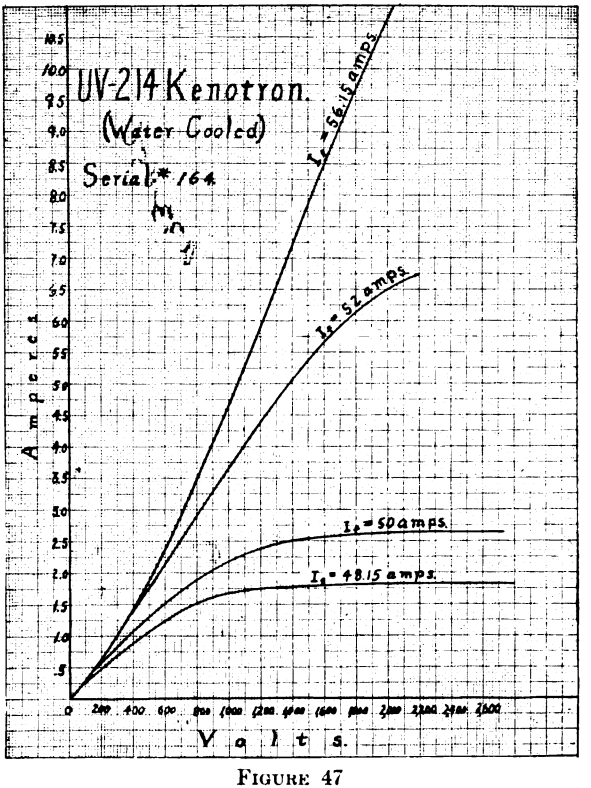

Figure 47

This equipment provides continuous wave and interrupted continuous wave telegraphy on wave lengths from 600 to 3,000 meters. The floor space required is ten square feet (1.08 sq. m.), and the over-all height is nine feet (2.74 m.). The equipment may be divided into two sections, the rectifier unit and the radio transmitter.

Referring to Figure 50 which shows the panel of the equipment, the left-hand section is the single phase, full wave kenotron rectifier, employing two UV-218 tubes.

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The rectifier is designed to operate from a 220-volt 60-cycle power supply. When the required voltage is not available, an auto transformer may be used.

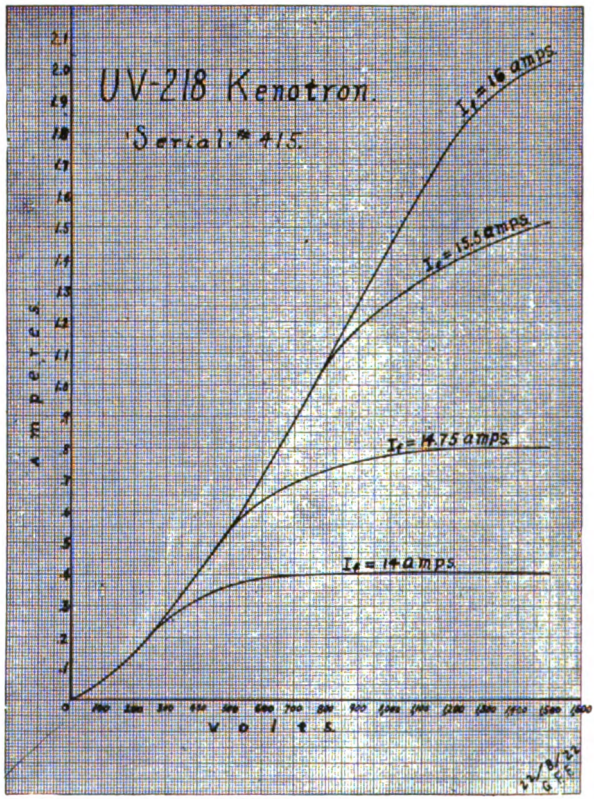

FIGURE 48

The upper portion of the panel contains the various meters required for control of the equipment. Directly below the meters are mounted three protective relays which prevent overloading the radiotrons sufficiently to destroy them. Below the protective relays is located the filament voltmeter transfer jack. The second section of the panel contains insulating switches for the filament and plate currents, as well as a line switch, rheostats for filament excitation control, and "stop" and "start" buttons. The lower section controls the power supplied, by means of taps on the auto transformer, thus providing a variation in the voltage impressed on the primary of the plate transformer, and permitting an adjustment of the output of the rectifier unit. The small

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handle controls an induction regulator which enables compensation for small changes in line voltage.

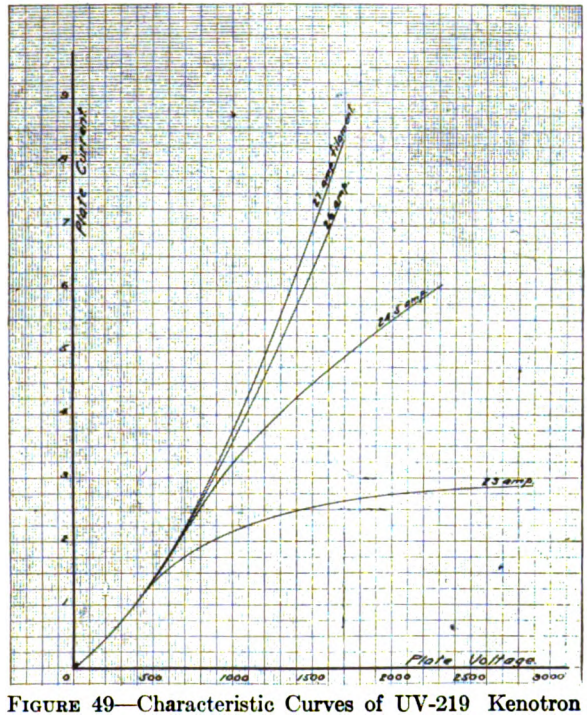

FIGURE 49—Characteristic Curves of UV-219 Kenotron

The lamps and buzzers mounted on the top of the panels are filament burn-out indicators. The left hand indicator is in the kenotron filament circuit, the other in the radiotron filament circuit. If a kenotron should burn out, the buzzer and lamp associated with this circuit would function. These units are designed to insert reactance in the filament circuit to prevent damaging the remaining tube in case of any increase in supply voltage, owing to the decreased load caused by the filament burning out.

The right-hand portion of the panel contains the control for the radio transmitter which employs two UV-206 radiotrons. The handle shown in the upper section provides means for selecting any one of three wave lengths between 600 and 3,000 meters. This wave change switch consists of a three position three bank switch so that, when changing wave lengths, it is only necessary to operate one switch which varies the constants

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of the antenna and associated circuits. The center section of the panel contains the keying relay, which is remotely controlled by the operator's telegraph key. The two-position switch below the keying relay selects the type of telegraph communication, that is, continuous wave or interrupted continuous wave.

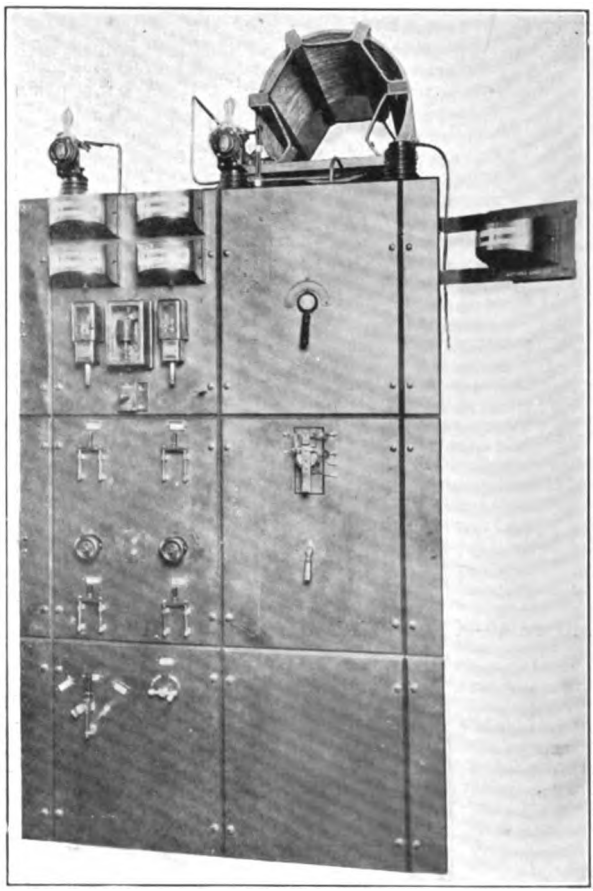

FIGURE 50—2 Kw. Radio Telegraph Transmitter, C. W. and I. C. W. Communication. Wave Length, 600 to 3,000 Meters

Complete control of the equipment is provided from the operator's desk. In addition to the telegraph key which controls the keying relay, two sets of push buttons are provided, "start" and "stop," "send" and "receive." The "start" and "stop" buttons control the main power contactor, which disconnects the power supply on the set side of the main line switch. The "send"

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and "receive" buttons control the necessary contactors and interlocking circuits required to connect either the transmitter or the receiver to the antenna in such a way as to prevent accidental starting of the transmitter when the receive button is depressed.

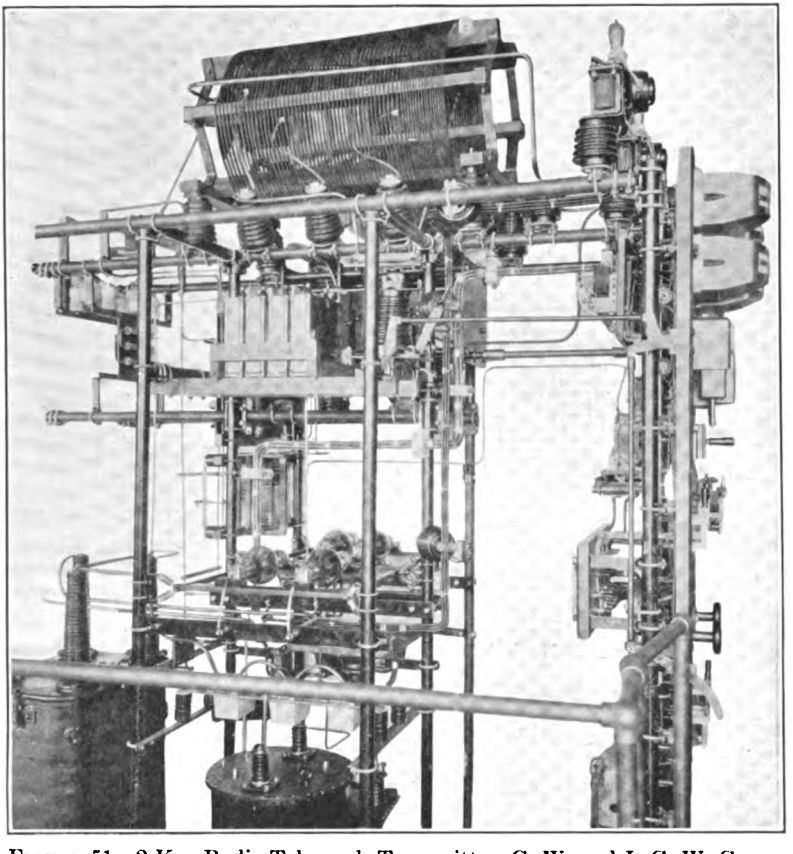

FIGURE 51—2 Kw. Radio Telegraph Transmitter, C. W. and I. C. W. Communication. Wave Length, 600 to 3,000 Meters

The circuit diagram of this equipment is shown in Figure 52.

A second type of two kilowatt fixed station and a 4 kilowatt equipment of the same general design is shown in Figure 53. These sets are designed to provide continuous wave telegraphy on any four wave lengths between 600 and 3,000 meters. The transmitter consists essentially of four component circuits. A rectifier circuit is used to obtain a source of high voltage direct current for the plate of the radiotron. The filter circuit is arranged to smooth out the ripple in the rectifier circuit current, an

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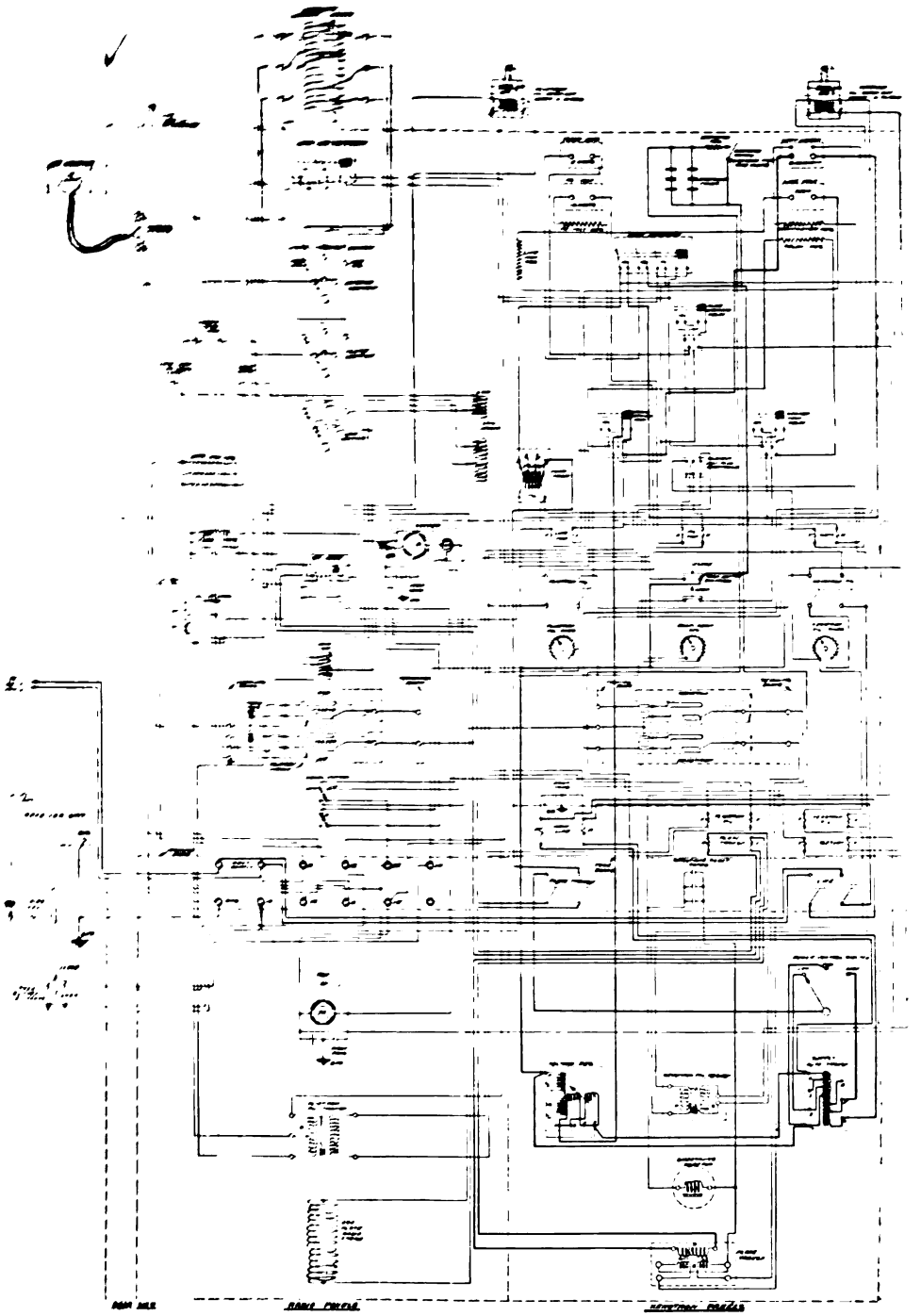

FIGURE 52—Circuit Diagram of 2 Kw. Transmitter

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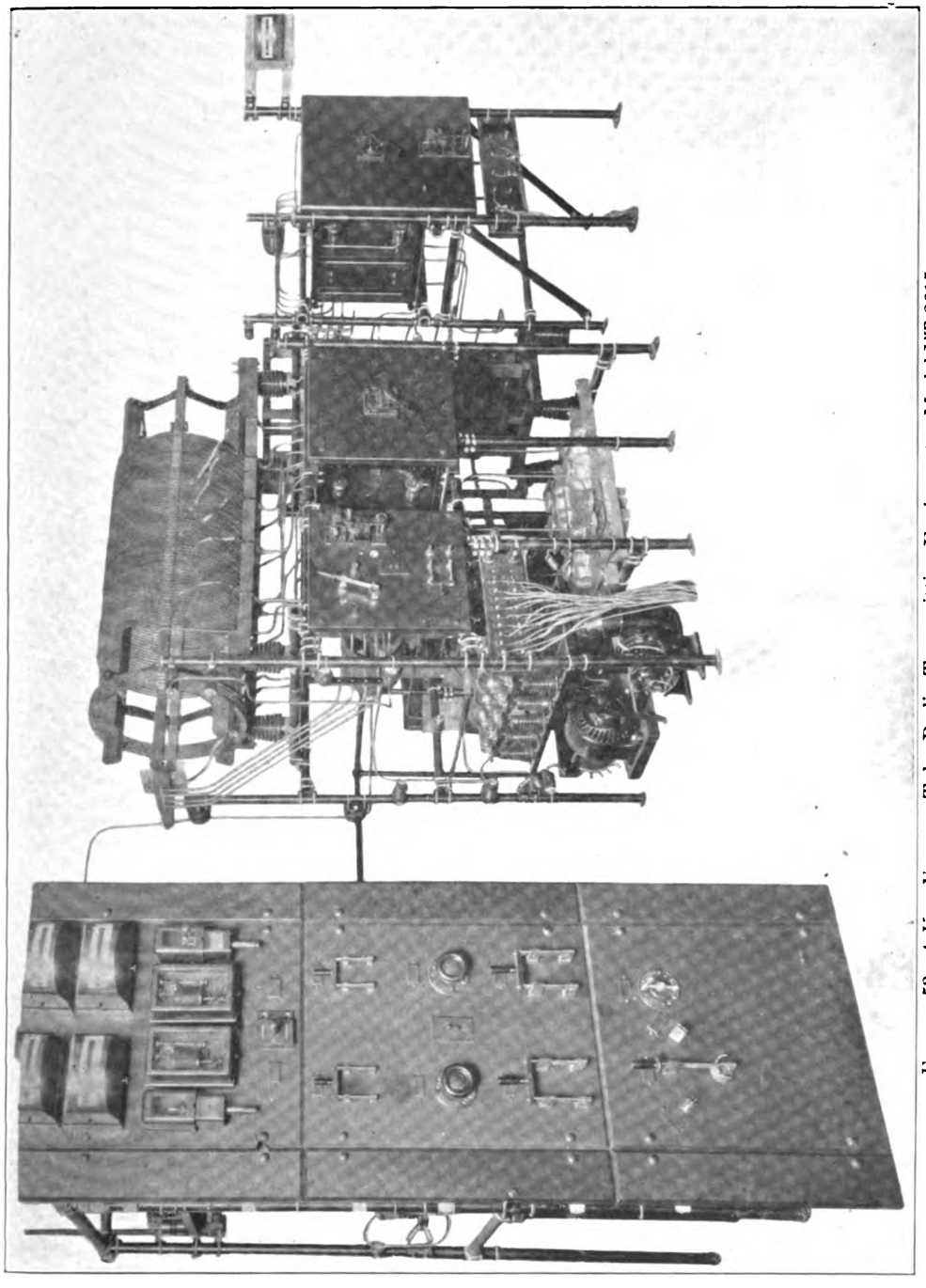

FIGURE 53—4 Kw. Vacuum Tube Radio Transmitting Equipment. Model ET-3615

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oscillator circuit is provided which converts the high voltage direct current output of the rectifier and filter into radio frequency current, and a tuning system is included by means of which the wave length of the antenna circuit is adjusted to the wave length of the transmitter. The transmitted wave length is established primarily by the tank circuit in the transmitter which is loosely coupled to the antenna circuit.

The foregoing circuits are built in three independent units:—a vacuum tube rectifier panel which contains the rectifying and filter circuits, a vacuum tube oscillator panel which contains the oscillator and antenna circuits, and an antenna tuning unit which includes the equipment necessary for adjusting the wave length of the antenna.

The rectifier for the 4 kilowatt transmitter is shown in Figure 54. Rectifying equipment for the 2 kilowatt transmitter is quite similar in design, except that only two UV-218 kenotrons are used instead of four. Both rectifiers operate in a single phase, full wave circuit, with 110 or 220-volt, 60-cycle supply.

The radio frequency generating units shown in Figure 55 use three UV-206 tubes, for the 2 kilowatt outfit, and five UV-206 tubes for the 4-kilowatt equipment. A schematic circuit diagram is given in Figure 56. Any one of the four wave lengths may be selected by means of the four bank switch. The units mounted on the left-hand panel of the transmitter are a switch for controlling the coupling, the keying relay, communication switch, and start-stop push button.

The antenna loading coil with its wave-change switch is shown in Figure 57.

Control is normally obtained by means of auxiliary equipment constructed for mounting on the operator's table. This equipment consists of a telegraph key with a back contact for operating the break-in relay, and the operator's signal and control cabinet which includes the following:

1. Start and stop switch, which opens and closes the main line contactor on the rectifier panel.
2. Tumbler switch for controlling a stand-by send-receive switch mounted in the antenna unit structure.
3. Three indicating drops, which indicate plate overload and kenotron or radiotron filament over-voltage, respectively. Each of the three drops actuate a buzzer which indicates to the operator that the transmitter requires attention. This control unit is shown in Figure 58.

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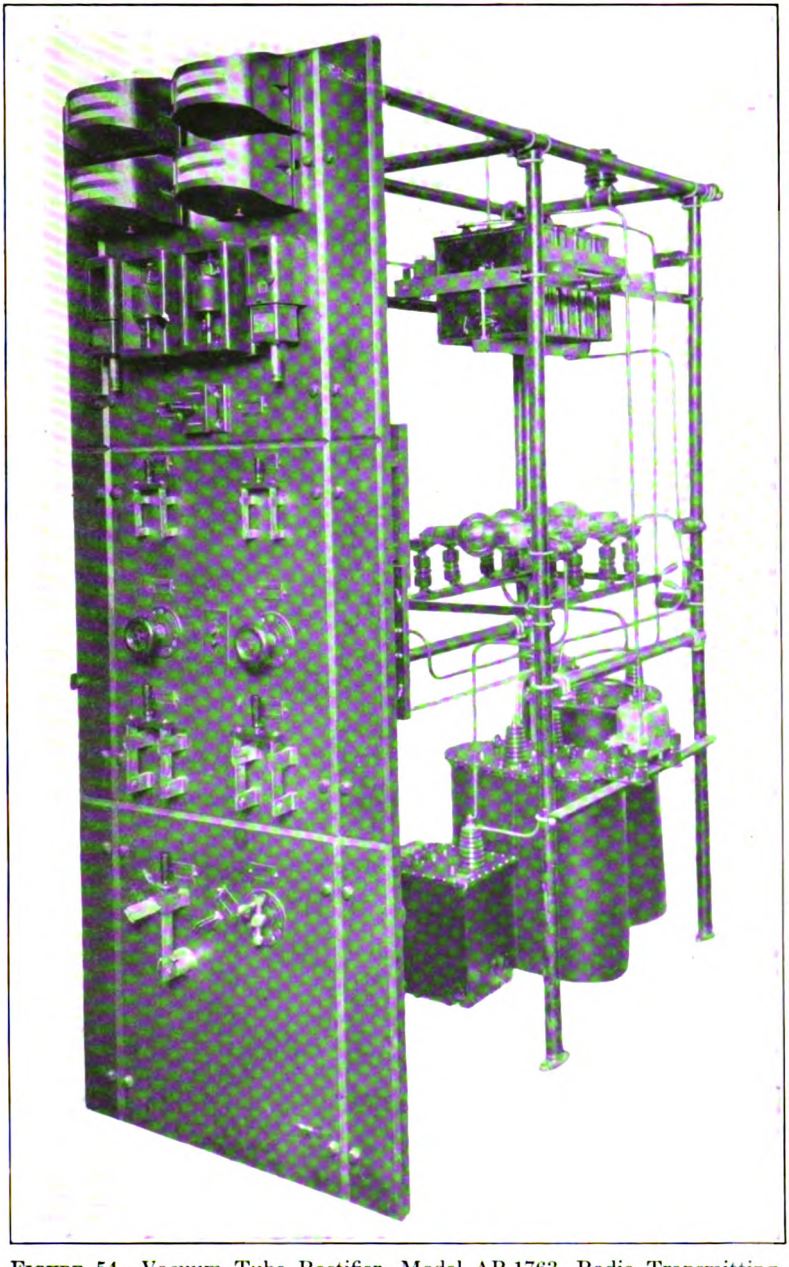

FIGURE 54—Vacuum Tube Rectifier, Model AP-1763, Radio Transmitting Equipment ET-3615

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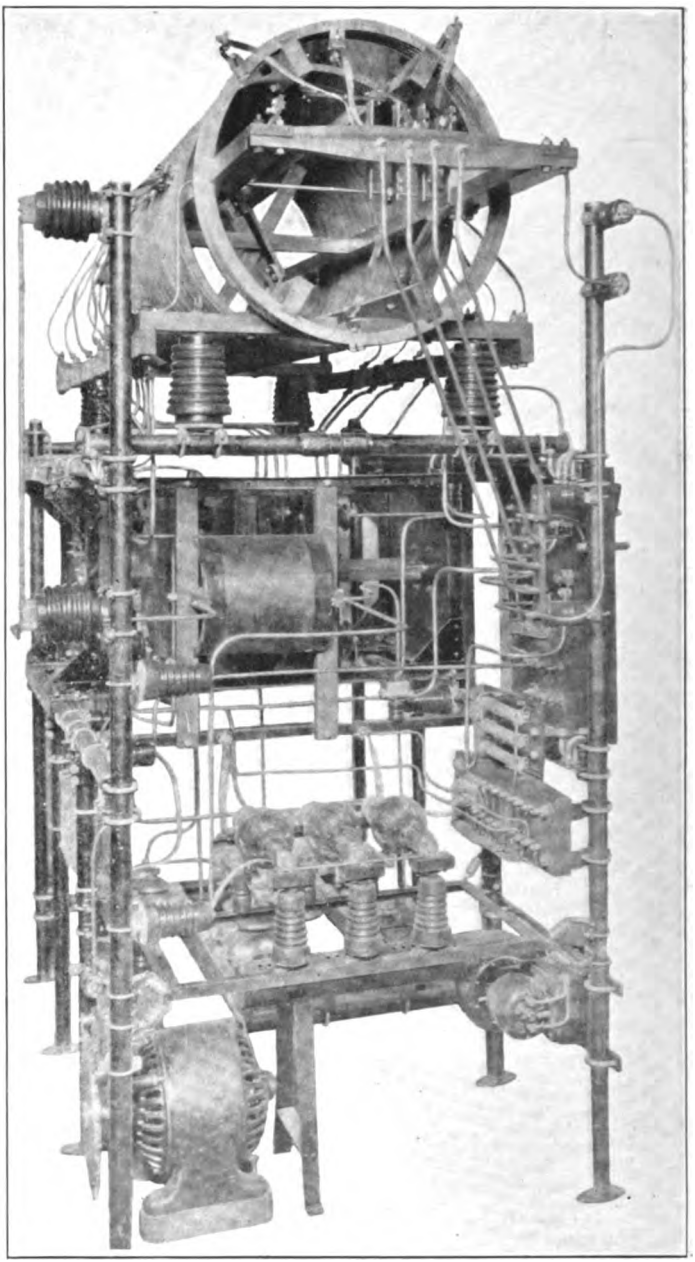

FIGURE 55—Vacuum Tube Oscillator, Model ST-1764, 2 Kw. Radio-Transmitting Equipment, Model ET-3613

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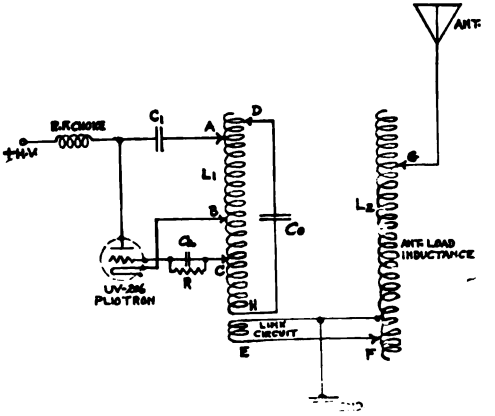

FIGURE 56—Schematic Diagram of Oscillating Circuits

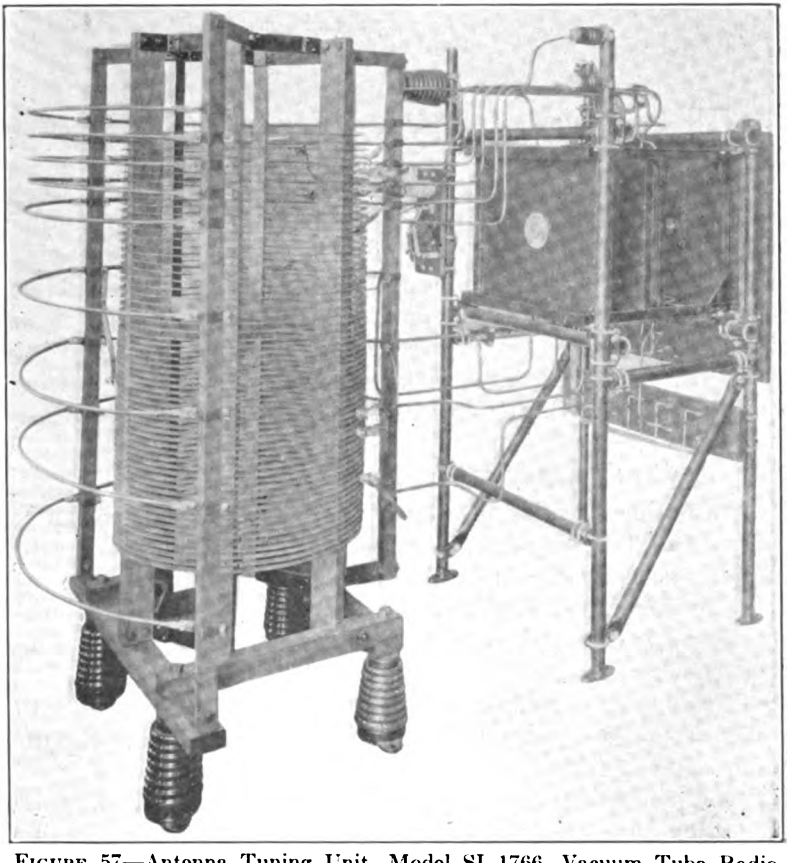

FIGURE 57—Antenna Tuning Unit, Model SL-1766, Vacuum Tube Radio Transmitting Equipment, Model ET-3615

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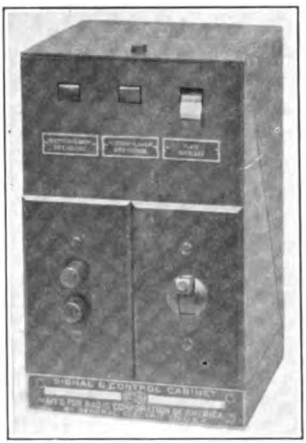

FIGURE 58—Signal and Control Cabinet

The control supplied for the operator's cable, while sufficient for normal operation, does not take care of all adjustments for the set. Wave change, power change, signal change, filament voltage control, and line voltage compensation are controlled in the transmitter. Provision is also made for starting and stopping the set from push buttons located on the rectifier and oscillator panels. The equipments are provided with protective apparatus which will prevent any injury to the component parts in the event that the apparatus is improperly operated. Operating characteristics of the UV-206 radiotron are shown in Figure 59.

20 KILOWATT TRANSMITTING EQUIPMENT

An outline drawing of a 20-kilowatt equipment is shown in Figure 60. This transmitter consists of three main units:—rectifier, master oscillator, and radio frequency generator.

The three phase double Y rectifier utilizes six UV-219 kenotrons and is designed to operate on a three phase, 220 or 440-volt 60-cycle circuit.

The master oscillator includes one UV-206 radiotron with sufficient accessory apparatus to provide a band of wave lengths from 2,500 to 4,500 meters.

The power amplifier is divided into three units, UV-207 tube mounting with complete cooling system comprising a radiator pump and fan, tank circuit variometer and tank condensers. Characteristics of the UV-207 radiotron are shown in Figure 61.

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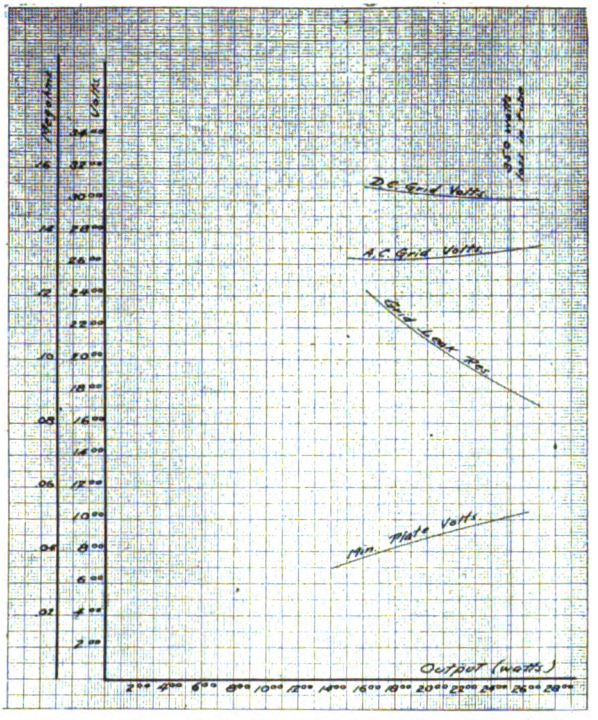

FIGURE 59A—Operating Characteristics of Typical UV-206 Radiotron

Some information on the radiotrons mentioned in this paper is given in the following table:

POWER TUBES

Model	Filament		Plate		μ	Output, Watts
	Volts	Amps.	Volts	Amps.		
UV-202	7.5	2.35	350	0.050	7.5	5
UV-203	10.0	6.50	1,000	0.150	15.0	50
UV-203A	10.0	3.25	1,000	0.125	25.0	50
UV-204	11.0	14.75	2,000	0.250	20.0	250
UV-204A	11.0	3.85	2,000	0.200	25.0	250
UV-206	11.0	14.75	10,000	0.125	250.0	1,000
UV-207	22.0	52.0	15,000	1.800	40.0	20,000
UV-208	22.0	24.5	15,000	0.450	300.0	5,000

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KENOTRONS

Model	Filament		Watts
	Volts	Amps.	Outputs (D.C.)
UV-214	22.0	52.0	50,000
UV-216	7.5	2.35	20
UV-217	10.0	6.5	150
UV-218	11.0	14.75	2,500
UV-219	22.0	24.5	12,500

RECEIVING TUBES

Model	Filament		Plate		μ
	Volts	Amps.	Volts	Amps	
UV-199	3.0	0.06	40	0.001	6
UV-200	5.0	1.0	18 to 23	0.0005 to 0.002	
UV-201	5.0	1.0	40	0.001	6
UV-201A	5.0	0.25	40	0.0012	6.5

OPERATING LIFE OF TUBES

One of the most important features of a vacuum tube is its operating life. The length of this operating life shows a wide variation with respect to operating conditions, and to some extent with respect to individual tubes of the same type.

For any given type of tube, life test conditions are decided upon from the best approximation to average operating conditions, and a considerable number of tubes are thus tested and average and maximum values of length of life determined.

Such average figures, however, are obviously not representative of the operating conditions of every individual user. These conditions vary widely, and it is, therefore, impossible for the tube manufacturer to guarantee a certain operating life to each user.

In the case of large power tubes, for a considerable time after manufacture of the tube has been under way, life test data are not obtainable. Life data furnished the user in such cases are

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then estimated and supplemented by data calculated from tubes having features most similar to the tube in question.

Tube failures fall into two general classes:

1. Normal or accelerated filament burn-outs.
2. Failures from causes other than filament burns-outs, which are traceable to incorrect use or defects in design or manufacture.

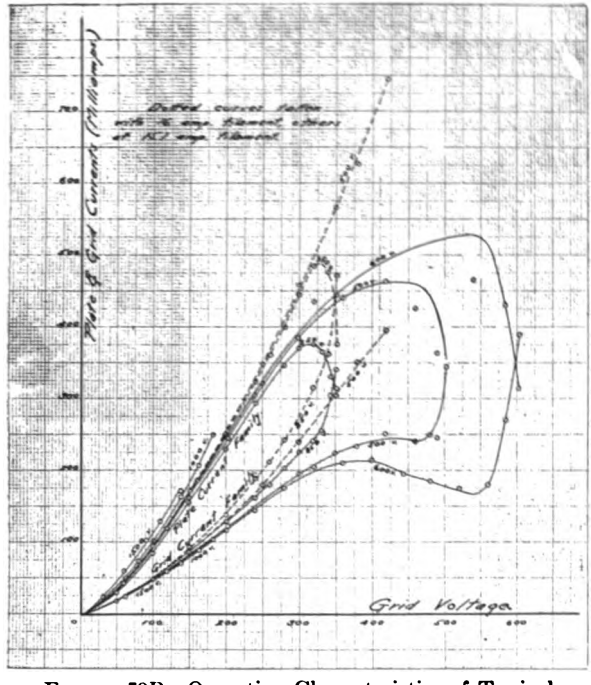

FIGURE 59B—Operating Characteristics of Typical UV-206 Radiotron

It would seem that the best policy in regard to life is to furnish for each type of tube what might be best termed a "life expectation" based on the average data obtainable. This figure, however, is in no sense a guarantee. If the user on actual records obtains a life so much shorter than the expected life that it cannot be reconciled with operating conditions, the tube should be inspected for the cause of the trouble. If this inspection shows a fault traceable to design or manufacture, this tube should be considered for adjustment or replacement.

This policy of tube life is only applicable to commercial installations where the operation is more or less routine and where

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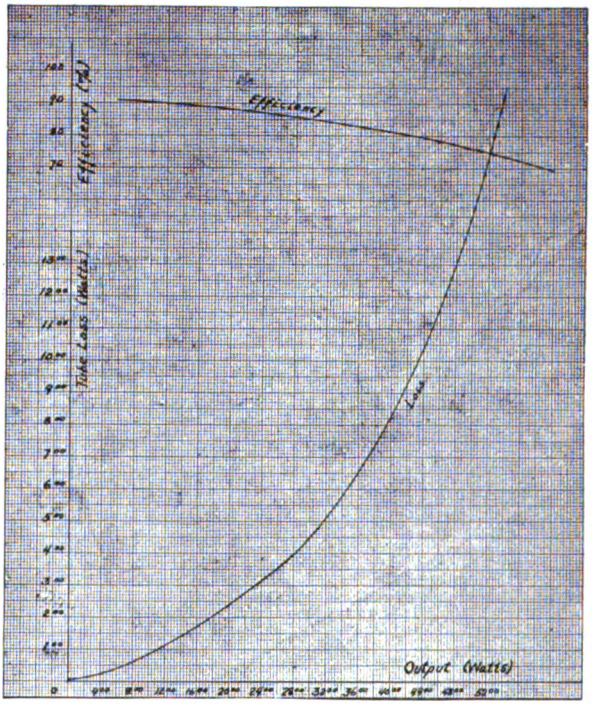

FIGURE 59C—Operating Characteristics of UV-206, Pliotron at 15,000 Volts D. C.

log sheets are maintained, so as to indicate with considerable accuracy not only the actual life obtained, but the conditions of operation. Tubes used for experimental purposes or where the conditions of operation are not controllable or made a matter of record, naturally cannot be considered in the way described.

SUMMARY: Tube transmitters for outputs from 500 watts to 20 kilowatts, and for continuous wave and interrupted continuous wave telegraphy and telephony are described in detail. The essential elements of such transmitters are discussed. Data are given on the characteristics of various power tubes and rectifiers, and a statement relative to the expectation of life of a tube.

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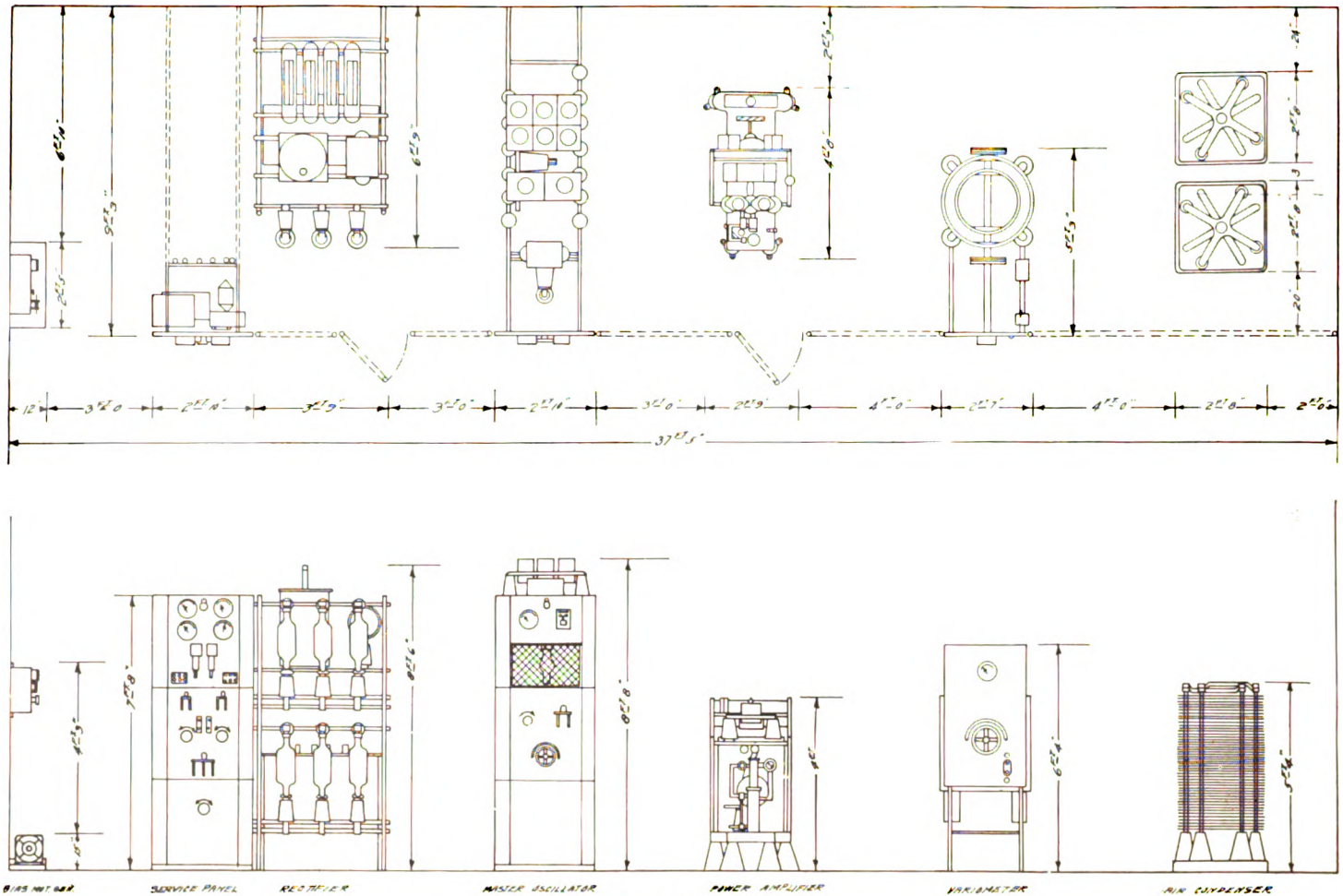

FIGURE 60—Outline of 20 Kw. Transmitter

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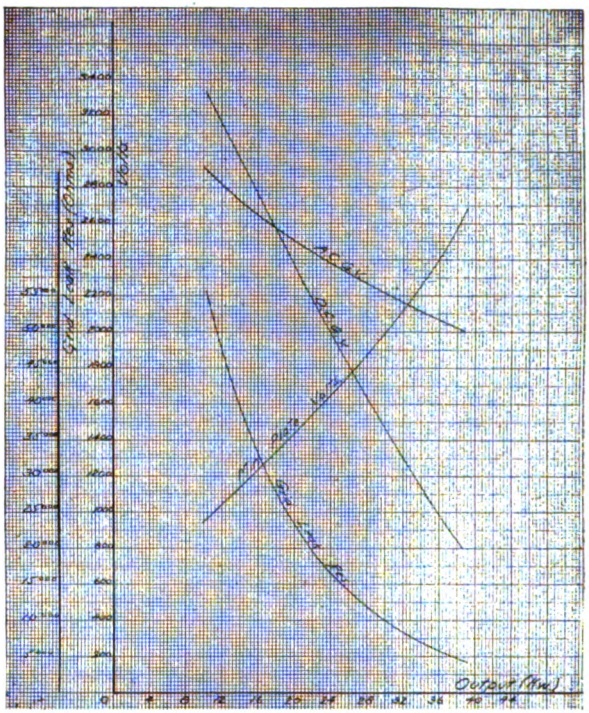

FIGURE 61A—Operating Characteristics of Typical UV-207, Radiotron

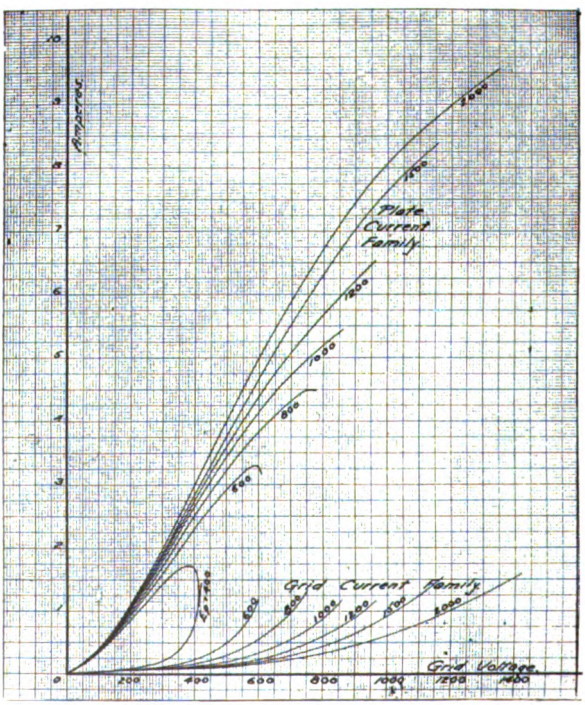

FIGURE 61B—Operating Characteristics of Typical UV-207, Radiotron

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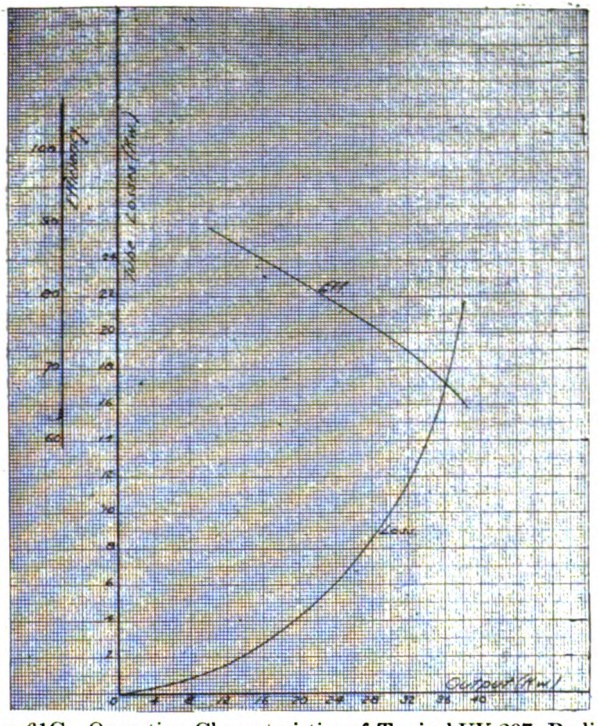

FIGURE 61C—Operating Characteristics of Typical UV-207, Radiotron

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RADIO TRANSMISSION MEASUREMENTS ON LONG WAVE LENGTHS*

By

H. H. Beverage

and

H. O. Peterson

(Engineering Department, Radio Corporation of America, New York)

(Communication from the International Union of Scientific Radio Telegraphy)

Introduction

For some time, the authors have been working on methods for the quantitative measurement of field strength. The authors now have developed a satisfactory method, but have not yet obtained any great amount of data on transmission over great distances, as it takes months and even years of observation before drawing general conclusions, because of the great variability of signals over great distances. It is the purpose of this memorandum to describe the method used, and some of the results obtained during the development of this apparatus.

Theory

The most reliable radio transmission formula known at present is the Austin-Cohen formula, which is as follows:

$$E = \frac{0.00126\, H_R\, H_T\, f I}{D} \times \textit{Absorption factor}$$

or

$$E = \frac{0.377 H_R H_T I}{\lambda D} \times \textit{Absorption factor}$$

where E = volts induced in receiving antenna

f = frequency in kilocycles per second

λ = wave length in kilometers

I = transmitter antenna current, amperes

H_T = effective height of transmitting antenna in kilometers

H_R = effective height of receiving antenna in kilometers.

*Received by the Editor, July 24, 1923. Presented before The Institute of Radio Engineers, New York, September 5, 1923.

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For daylight transmission over sea, Austin gives the absorption factor as:

$$\epsilon^{-0.00087 D\sqrt{f}} \text{ or } \epsilon^{-\frac{0.0015 D}{\sqrt{\lambda}}}$$

where ϵ is the base of Napierian logarithms.

In the above formula, the factors which are directly measurable are antenna current I, frequency f or wave length λ, and distance D. The other three factors H_R, H_T, and absorption factor, can be calculated with some degree of accuracy, but it is very desirable to measure them by a precision method. It is fairly easy to measure any one of these three factors, if the other two are known.

The general method which the authors propose for separating these three factors, H_R, H_T, and absorption factor, is as follows:

First:—Calibrate the receiving antenna effective height, H_R. It is very difficult to calculate the effective height of a vertical receiving antenna accurately, as it depends upon the proximity of surrounding structures, ground conditions, and so on. However, the effective height of a loop may be calculated easily, and may be used to calibrate any desired antenna, provided the effective height of the loop actually agrees with its theoretical calculated value. The authors spent considerable time checking this point, as will be described later.

Second:—Using the calibrated receiving antenna, measure the field strength in microvolts per meter within a few wave lengths of the transmitting station, at which point the absorption is negligible, making the absorption factor unity. This measurement gives H_T, the effective height of the transmitting station.

Third:—Knowing the effective height of the receiving and transmitting antennas, measurements made at a great distance should give the absorption factor.

Apparatus for Measurement of Field Strength

The received currents are very minute, so special methods are necessary to measure them. There are several methods, but the most direct method and the one preferred by the writers is the radio frequency comparison method. It consists in substituting an artificial signal voltage for the signal, and adjusting for equality between the artificial and actual signal. Then, by measuring the artificial signal voltage, the voltage due to the signal itself becomes known. If the artificial signal is intro-

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duced into the antenna, the comparison should be independent of antenna resistance or receiver sensitivity.

Several investigators have developed apparatus for measuring signal intensity by the radio frequency method. The methods used consist simply of synchronizing a local oscillator with the incoming signal, measuring the current in the oscillating circuit or an associated circuit, and then introducing the voltage into the antenna thru a calibrated arrangement to control the intensity of the voltage introduced into the antenna.

Engineers of the Western Electric Company and the American Telephone and Telegraph Company have devised a method whereby the current in the oscillator is measured on a sensitive thermo-couple meter, and then introduced into the antenna thru a calibrated cable mile box. This method was recently described in a paper before THE INSTITUTE OF RADIO ENGINEERS by Messrs. Bown, Englund, and Friis.[1]

In England, Mr. H. J. Round and his associates devised a measuring outfit in which the current in an intermediate circuit is determined by measuring the voltage across the intermediate circuit tuning condenser by the "slide back" method, and introducing the voltage into the antenna by means of a calibrated mutual inductance. Messrs. Weinberger and Dreher described a method using a calibrated mutual inductance for introducing the voltage into the antenna directly. (PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS, volume 7, number 6, page 584, December, 1919.)

The authors decided that the ideal measuring outfit should be similar to the Marconi outfit, but should have a direct reading meter for the oscillator current, rather than measuring the current by the more cumbersome "slide back" method. Accordingly, the authors developed the measuring outfit shown schematically in Figure 1.

This outfit requires little explanation. It consists essentially of an oscillator contained in a shielded compartment complete with filament and plate batteries. A UV-199 tube is used as the oscillator. The plate and grid coils are placed end to end in a honeycomb coil mounting, the windings progressing in such a manner as to form an astatic pair. The intermediate circuit inductance is coupled to the oscillator. In the intermediate circuit is a tuning condenser, a sensitive thermo-couple, and a relay for interrupting the circuit. Associated with the inter-

[1] See PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS, volume 11, number 2, page 115, April, 1923.

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mediate circuit is the mutual inductance which introduces the artificial signal voltage into the antenna.

The voltage introduced into the antenna by this means is easily obtained from the relation:

$$E = I\,\omega\,M \text{ volts}$$

where I = current in the intermediate circuit as indicated by thermo-couple meter, amperes

$\omega = 2\pi \times$ frequency in cycles per second

M = mutual inductance in henrys.

If the intermediate circuit is omitted, the error due to harmonics is about 2 percent or 3 percent, which may be neglected on measurements on distant signals, since the error of measurement is greater than 3 percent anyway.

Method for Using Measuring Outfit

The mutual inductance may be connected into any form of antenna, either vertical antenna, loop antenna, wave antenna, or any circuit in which the induced voltage is to be measured. In case a loop antenna is used, it is usually necessary to place the mutual inductance in the center of the loop, grounding the mid-point of the secondary side of the mutual inductance. In the case of a vertical antenna, the mutual inductance may be placed at any point in series with the antenna lead-in; that is, it may be placed either on the antenna or the ground side of the receiver primary inductance, but it must not be shunted by a variable condenser. If a variable condenser is used in shunt to the primary inductance, it must not shunt the mutual inductance, as this would cause the mutual inductance voltage to be introduced into a circuit of different impedance than that offered to the real signal voltage. If this one precaution is observed, it will be found that the measurements are correct, practically independently of the antenna constants.

The greatest error in measurement of signals is in the equalzing of artificial and real signal voltages. If the signals are weak nd are associated with considerable static, the usual method to equalize by ear, by "chipping in;" that is, the local oscillator keyed at intervals between the real signals, and the intensity the artificial signal adjusted until it sounds exactly the same the real signals. The ear cannot distinguish differences less an about 30 percent ordinarily, but after practice, it is usually ssible to make the setting within 20 percent to 25 percent, or ser if static interference is not too heavy.

If the signal to be measured is considerably above the static,

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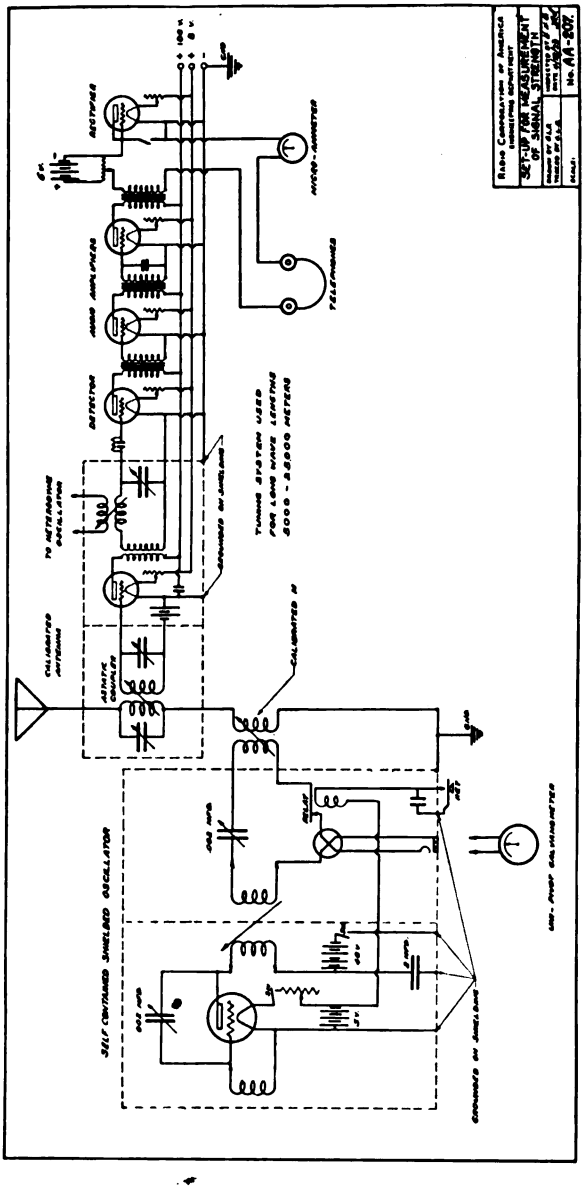

FIGURE 1

and the transmitting station is co-operating, measurements may be made within 2 percent or 3 percent. For this work, the signals are amplified and rectified, the rectified current being read on a direct current micro-ammeter. The transmitter makes a dash of several seconds' duration, and the direct current meter

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deflection is noted. Then the transmitter is silent while a dash is made on the local oscillator and the mutual inductance adjusted to give the same deflection. This method is very accurate, since the deflection is proportional to the square of the antenna current, and a slight change in voltage makes a large change in deflection.

If the transmitter is not co-operating, it is still possible to get a fair accuracy with the direct current meter, as the meter will indicate just half maximum deflection when the transmitter sends a series of dots, which occurs whenever the tape on the automatic transmitter runs out. On high speed transmission, the deflection is also about half, but not so steady or precise as the dots, the latter being about as accurate as a dash.

All of the measurements on local transmitters were made with co-operative dashes in the manner described above.

Calibration of Receiving Antenna

For measuring distant signals, it is usually desirable to work with antennas of fairly high effective height, as this allows the use of larger mutual inductances, larger thermo-ammeters, less possible error from stray fields, and so on. However, it is necessary to calibrate the effective height of the vertical antenna. At Belmar an antenna about 30 meters (98 feet) high with a flat top 39 meters (98 feet) long was available. This antenna was compared with a large single turn loop, which gave an effective height of about 11.25 meters (37 feet) for the vertical antenna. As this seemed low, the authors built several other loops of various sizes, shapes, and number of turns. Hundreds of measurements were made comparing these loops with the vertical antenna, but the average result was 11.25 meters (37 feet) for the effective height of the vertical antenna. Correction formulas were also developed for loops of various shapes.

The simplest form of loop is a single turn rectangular loop. It may be considered as two opposed vertical antennas equal to the height of the rectangle, and having a phase difference equal to the length of the loop, thus:

$$H = 2\,h \sin \frac{\pi b}{\lambda}$$

or

$$H = 2\,h \sin \pi b \left(\frac{f}{300{,}000}\right)$$

where h = the height of the loop in meters
b = length of loop in meters
f = frequency in kilocycles per second
λ = wave length in meters.

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If the length of the loop is not over one-sixth of a wave length, the angle is small, so the angle is equal to the sine of the angle, and we have

$$H = \frac{\pi h b f}{150{,}000} \quad \text{or} \quad H = \frac{2\pi h b}{\lambda}$$

Since $h \times b$ = area of the loop, we can write

$$H = \frac{\pi N A f}{150{,}000} \quad \text{or} \quad H = \frac{2\pi N A}{\lambda}$$

where N = number of turns
A = area of loop.

For a triangle loop, there is a correction factor to correct for progressive phase differences of the increments of voltage along the sloping sides of the loop. This factor is given below.

For triangular loops

$$H = \frac{2\pi N A}{\lambda} \times \frac{b}{\lambda \sin^{-1}\left(\frac{b}{\lambda}\right)}$$

The correction factor

$$\left[\frac{b}{\lambda \sin^{-1}\left(\frac{b}{\lambda}\right)}\right]$$

may be neglected excepting for very large triangular loops.

There were some interesting points found in checking up the effective height of loops. One large rectangular loop came out about 20 percent low, apparently because of shielding from the steel supporting tower. Another interesting observation was made on a 20-turn loop 30 ft. (9.2 m.) high by 80 ft. (24.4 m.) long. It was found that the effective height decreased with decrease in wave length, whereas it should increase with decrease in wave length. The observed effective height of this loop is plotted as curve A, in Figure 3, while the calculated effective height is shown as curve B. The station wave antenna ran within 15 feet (4.6 m.) of this loop and was found to be responsible for these peculiar results. Upon opening the wave antenna at a distance of 200 meters (656 ft.) from the station, the measured values were found to be approximately the same as the calculated value, as shown by the points plotted on the curve B of Figure 3.

From our many observations on the various loops, it is apparent that the simple calculation of the effective height of loops is substantially correct, but that care must be taken to avoid shielding, or coupling to other wire systems.

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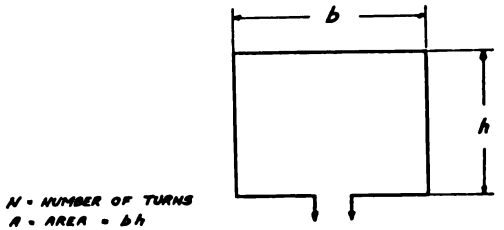
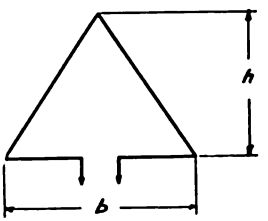


N = NUMBER OF TURNS
A = AREA = bh

EFFECTIVE HEIGHT $H = 2hNSin\left(\frac{\pi b}{\lambda}\right)$

$= \frac{2\pi NA}{\lambda}$ APPROX.



N = NUMBER OF TURNS
A = AREA = $\frac{bh}{2}$

EFFECTIVE HEIGHT $H = 2hNSin\left(\frac{\pi b}{2\lambda}\right) \times \left[\frac{b}{\lambda Sin^{-1}\left(\frac{b}{\lambda}\right)}\right]$

$= \frac{2\pi NA}{\lambda} \times \left[\frac{b}{\lambda Sin^{-1}\left(\frac{b}{\lambda}\right)}\right]$ APPROX

FIGURE 2

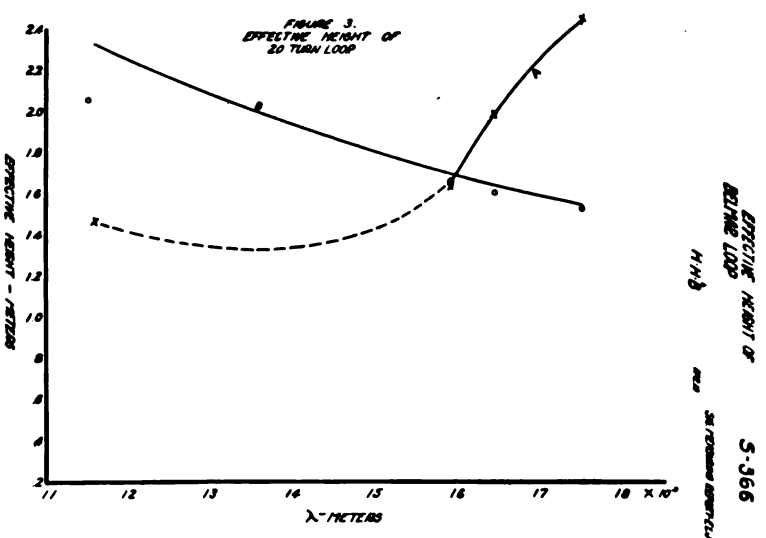


FIGURE 3

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Results of Measurements

The results of the average of all measurements made on the local transmitters of the Radio Corporation are given in Table 1. In order to eliminate all error due to absorption, measurements should have been made closer to the stations. As the authors were not prepared to do this, the absorption was calculated by the Austin-Cohen formula. From an inspection of the table, it is evident that the error would not exceed 5 percent if the absorption were neglected, with the exception of Marion, where the calculated absorption factor is 0.87. Marion is the only station which came much lower than the estimated effective height, and it is probable that, due to overland absorption, the received energy is less than the calculated energy for oversea absorption, and therefore the effective height of Marion is nearer the estimated value than the measured value. Both of the Tuckerton stations appear to be estimated too low, while the other stations are nearly correct.

TABLE 1

Location	Station Call	Frequency Kilocycles	Wave Length Meters	Radiation Amperes	*d* Distance in Km.	Calculated Absorption Factor-Oversea
Radio Central..	WQL	17.13	17,500	603	125	0.952
Radio Central..	WQK	18.22	16,450	679	125	0.950
Tuckerton.....	WGG	18.86	15,900	469	69.5	0.974
Tuckerton.....	WCI	17.25	16,800	350	69.5	0.975
New Brunswick	WII	22.06	13,600	576	50	0.980
Marion.....	WSO	25.96	11,550	530	322	0.870

	Calculated Microvolts per Meter, Belmar	Measured Microvolts per Meter, Belmar	Calculated Effective Height, Meters	Measured Effective Height, Meters
WQL.....	8,200	8,130	83	82.3
WQK.....	9,700	10,440	83	89
WGG.....	8,860	10,470	57	67
WCI.....	6,290	7,510	57	68
WII.....	21,300	20,820	68	66.5
WSO.....	3,170	2,825	68	60.5*

* Doubtful because of overland attenuation.

During March, measurements were started on distant signals, using the vertical antenna of 11.25 meters (37 feet) effective height. In the morning when static was light, it was possible

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to use the meter deflection method for equalizing the distant and artificial signals. In the afternoon, it was necessary to use the "chip in" aural method, as the static made the deflection method unworkable. The results of these measurements are shown in Table 2.

There are too few observations to draw any conclusions yet. The European signals seem abnormally high, but it is believed that the measurements are reasonably correct, since the same measuring outfit checks so closely on local signals.

No static intensity measurements are included with these long distance measurements, but work is proceeding in that direction. One method used with considerable success in Brazil consisted in estimating the readability of the measured signal. When the static was stronger than the signal, the local oscillator was keyed and its intensity increased until it could be read at a speed of 20 words per minute.

This measurement gave the microvolts per meter required to read 20 words per minute thru the noise due to the static, 20 words per minute being considered the working speed for code with a ratio of static noise to signal of unity. The curve shown in Figure 4 gives the working speed in five letters words for code, plotted against ratio of static to signal. A ratio of 2.5 gives a readibility of 9 words per minute, and anything below that is considered unreadable commercially. Nine words per minute is usually taken as 18 words per minute double sending.

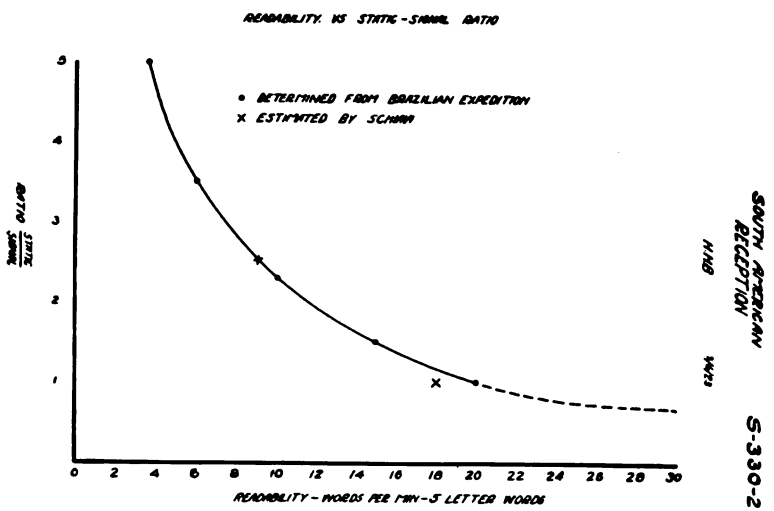
READABILITY VS STATIC-SIGNAL RATIO
• DETERMINED FROM BRAZILIAN EXPEDITION
× ESTIMATED BY SCHANN
RATIO STATIC / SIGNAL
READABILITY - WORDS PER MIN - 5 LETTER WORDS
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
1 2 3 4 5
SOUTH AMERICAN RECEPTION
NAA
S-330-2

FIGURE 4

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TABLE 2

BELMAR, NEW JERSEY—SIGNAL STRENGTH—MICRO-VOLTS/METER

Date	POZ Nauen, Germany		KET Bolinas, California, U. S. A.		MUU Carnarvon, Wales		UFT St. Assise, France		LCM Stavanger, Norway	
	10 A. M.	3 P. M.	10 A. M.	3 P. M.	10 A. M.	3 P. M.	10 A. M.	3 P. M.	10 A. M.	3 P. M.
March 26	112	51	109		89	78	118	78	21	
27	94	95	73	74	90	50	102	106		
28	89	66	69	87	69	76	115	97	44	
29	75	51	74	83	58	42	129	91		
30	80	76	74	68	61	35	120	112	27	
31	76	46	80	75	80	92	118	98		
April 2	49	66	57	93	57	44				
5		42		53		31		80		
7	74				72		132			
17	59	54		46	61	18	85	74		
18	49	20		56	69	64	101	47		
19	64	16	51	55	52	46	73	35		
20	60	23	85	57	52	71	81	43		
21	50		49		43		111			
23	49	30			54	51	82	70		
25	37	11		69	53	42	92	36		
26	52	21	52	73	61	58	75	35		
27	60	29	59	62	57		68			
28	66		65		46		107			
30	59	38		55	58	53	89	63		
May 1	51	46	39	61	56	70	93	62		
2	63	34		62	68	63	85	40		
3	63		63		53		79			
Average	65	42.4	66.6	66.4	61.8	54.7	97.9	67.5	30.7	

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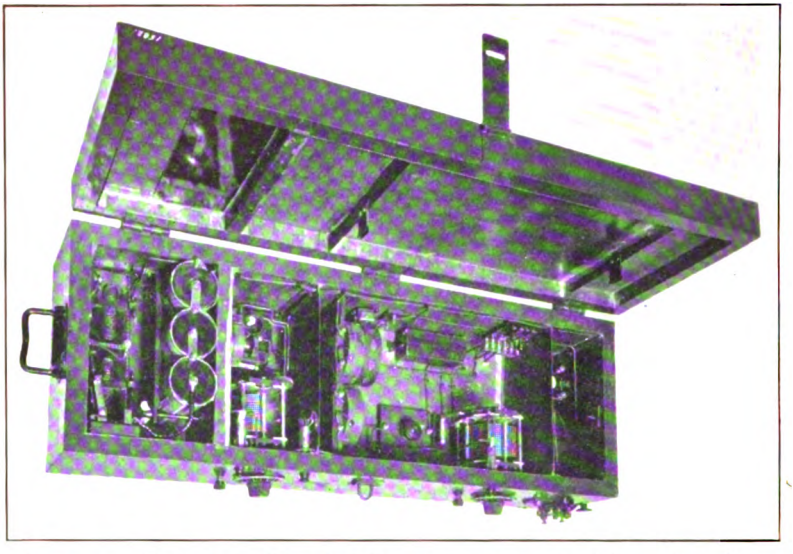

FIGURE 5—Shielded Oscillator for Measurement at Signal Intensity (Top View, Open)

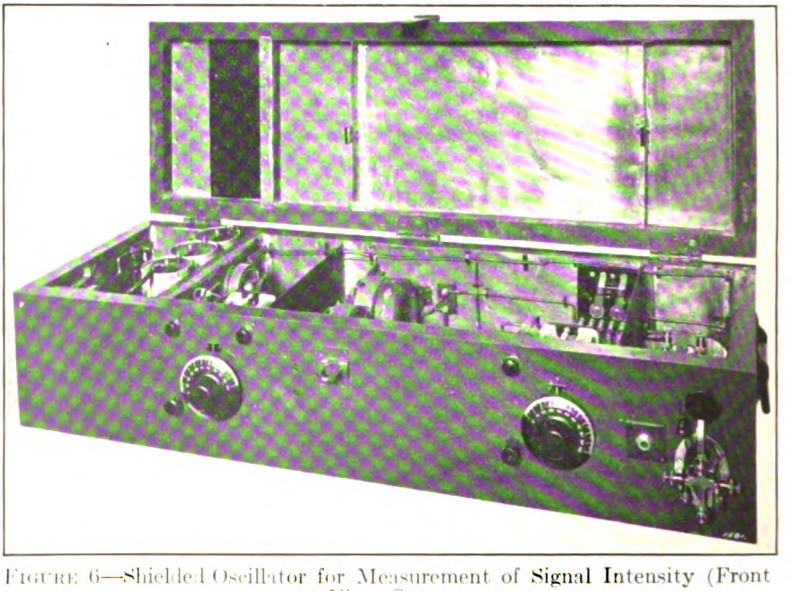

FIGURE 6—Shielded Oscillator for Measurement of Signal Intensity (Front View, Open)

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Conclusion

By the methods described above it has been found possible to

(1) Calibrate the effective height of a receiving antenna by comparison with loops.

(2) Measure the effective height of local transmitting antennas with an accuracy of about 3 percent.

(3) Measure distant signals to within 25 percent with bad conditions, and closer during good conditions. When sufficient data has been collected on distant signals, it should be possible to determine accurately the absorption term for long wave lengths over great distances.

May 22, 1923.

SUMMARY: A method of measuring the strength of received signals is described, both as to theory and apparatus employed

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STATIONARY WAVES ON FREE WIRES AND SOLENOIDS*

By

A. Press

(Chevy Chase, Maryland

Disregarding radiation phenomena, which naturally affect our conceptions both of the capacity and inductivity coefficients, stationary wave phenomena require a solution of the equations:

$$L_x \cdot \frac{di}{dt} = -\frac{de}{dx}; \quad C_x \cdot \frac{de}{dt} = -\frac{di}{dx} \tag{1}$$

Taking the case of a free solenoid coupled to a driver circuit (see Figure 1), it follows that the self-induction coefficient (zero frequency) would be greatest per unit of length near the middle of the coil rather than toward the free ends. Similarly the electrostatic flux (zero frequency) should be greatest per volt near the coil center than with respect to the free ends of the coil.

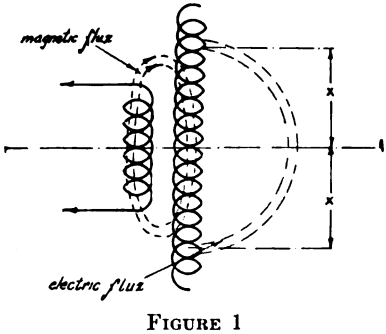

Figure 1

As a consequence of the above zero frequency conditions, the variable coefficients L_x, C_x give rise to nodal and antinodal current and voltage conditions similar to what takes place in a power circuit treated after the manner of a system of parallel wires, with the one wire acting as current return for the other. In the ordinary power circuit we have L_x and C_x constants.

* Received by the Editor, April 9, 1923.

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However, for the coupling coil, or, free wire, with a nodal point of emf. always at the center, it is necessary to take L_x and C_x as functions of x, where the x is measured outwardly from the center.

It will be observed that in the ordinary parallel wire circuit we always have that

$$c^2 = \frac{1}{LC} \tag{2}$$

so that if L is calculated, the C follows immediately, by virtue of the above reciprocal theorem. In other words, the L and C vary inversely with respect to each other. Nevertheless, in the case of a free coil or wire, it is seen that L_x and C_x can vary proportionately to each other. This is an important distinction and gives rise to the result that the nodal distances fall off in value as the ends are approcahed. (See experiments of Professor Townsend.)

On separating out the voltage and current functions in (2) we have

$$\begin{aligned} \frac{d^2 e}{dx^2} + L_x \cdot \frac{d}{dx}\left(\frac{1}{L_x}\right) \frac{de}{dx} &= L_x C_x \cdot \frac{d^2 i}{dt^2} \\ \frac{d^2 i}{dx^2} + C_x \cdot \frac{d}{dx}\left(\frac{1}{C_x}\right) \cdot \frac{di}{dx} &= L_x C_x \cdot \frac{d^2 i}{dt^2} \end{aligned} \tag{3}$$

If then the forced frequency of the sinusoidally sustained oscillations corresponds to the formula

$$p = 2\pi f \tag{4}$$

equations (3) are of the form

$$\frac{d^2 e}{dx^2} + \frac{1}{\phi(x)} \cdot \frac{d}{dx}\phi(x) \cdot \frac{de}{dx} + \frac{LCp^2}{(\phi x)^2} = 0 \tag{5}$$

provided we set

$$\begin{aligned} L_x &= \frac{L}{\phi(x)} \\ C_x &= \frac{C}{\phi(x)} \end{aligned} \tag{6}$$

In equations (6), the quantities L and C are constants and $\phi(x)$ is any arbitrary function of x depending on physical conditions.

The general solution of the equation (5) is of the form

$$e = A \cdot \sin nf(x) + B \cdot \cos nf(x) \tag{7}$$

provided we satisfy the relations

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$$\frac{d}{dx}f(x)=\frac{1}{\phi(x)} \tag{8}$$

$$LC\,p^2=n^2 \tag{9}$$

The proof is as follows: With

$$e=A\,.\,sin\,nf(x)+B\,cos\,nf(x)$$

we have

$$\frac{de}{dx}=n\{A\,.\,cos\,nf(x)\,.f'x-B\,.\,sin\,nf(x)\,.f'x\} \tag{10}$$

and therefore

$$\frac{1}{f'x}\cdot\frac{de}{dx}=n\{A\,.\,cos\,nf(x)-B\,.\,sin\,nf(x)\} \tag{11}$$

Operating once more with d/dx it follows

$$\begin{aligned}\frac{1}{f'x}\cdot\frac{d^2e}{dx^2}+\frac{d}{dx}\frac{1}{f'x}\cdot\frac{de}{dx}&\\ =-n^2\{A\,.\,sin\,nf(x)+B\,.\,cos\,nf(x)\}\,.f'x&\\ =-n^2\,.f'x\,.\,e&\end{aligned} \tag{12}$$

Thus multiplying thru with $f'x$ the latter reduces to

$$\frac{d^2e}{dx^2}+f'x\,.\,\frac{d}{dx}\frac{1}{f'x}\cdot\frac{de}{dx}+n^2(f'x)^2\,.\,e=0 \tag{13}$$

According to equation (5), therefore, it is necessary that the following relations be satisfied:

$$\begin{aligned}\frac{d}{dx}f(x)&=\frac{1}{\phi(x)}\\ n^2(f'x)^2&=\frac{LCp^2}{(\phi x)^2}\end{aligned} \tag{14}$$

The latter equations clearly indicate that we must have

$$LC\,p^2=n^2 \tag{15}$$

April 6, 1923.

SUMMARY: The production of stationary waves on systems having distributed electrical constants is mathematically treated.

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DIGESTS OF UNITED STATES PATENTS RELATING TO RADIO TELEGRAPHY AND TELEPHONY*

ISSUED AUGUST 28, 1923–OCTOBER 23, 1923

BY

JOHN B. BRADY

(PATENT LAWYER, OURAY BUILDING, WASHINGTON, D.C)

1,465,546—H. P. Donle, filed February 11, 1921, issued August 21, 1923. Assigned to Connecticut Telephone amd Telegraph Company.

INDUCTANCE constructed upon a flap form having tapered arms between which the consudctor is spirally wound. A zigzag course is imparted to the conductor with sharp change in direction of the conductor as it bends over the edges of each arm adjacent the slots between the arms.

1,456,932—E. H. Colpitts, filed September 11, 1915, issued August 28, 1923. Assigned to Western Electric Company, Incorporated.

MULTIPLEX RADIO TELEGRAPH SYSTEM, in which a plurality of messages are transmitted simultaneously from one or several stations and may be received simultaneously on one antenna or on a plurality of antennas located at the same place or at various places. At the transmitting station a plurality of different frequencies are radiated. At the receiving station the distinct frequencies are received. A local source of oscillations is provided which reacts separately with each of the received frequencies producing differing beat frequencies, which are utilized in separate circuits for selectively receiving the several messages.

1,465,961—E. F. W. Alexanderson, filed April 19, 1916, issued August 28, 1923. Assigned to General Electric Company.

RADIO SIGNALING SYSTEM for overcoming the effect of static disturbances in radio reception. The transsmitter is arranged

* Received by the Editor, November 10, 1923.

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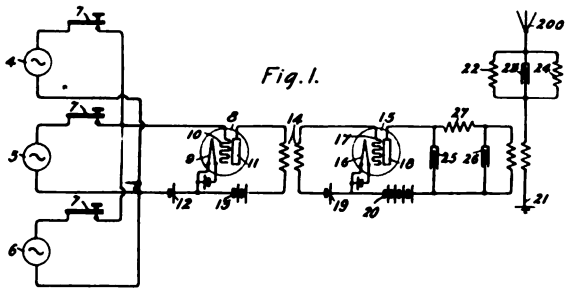
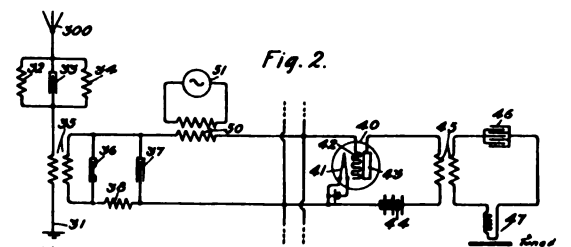
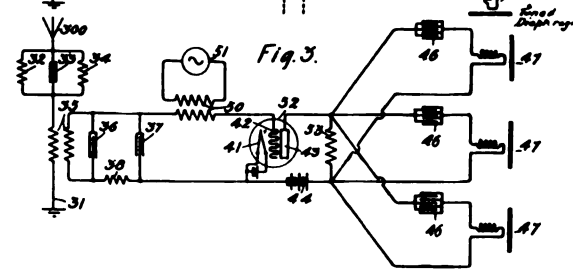
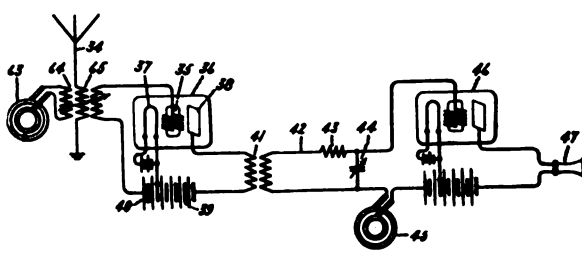
to radiate the radio frequency signals simultaneously on two different wave lengths. At the receiving station both of these waves are simultaneously received. The two sets of waves interact to produce a current having amplitude pulsations of a frequency equal to the difference between the two radio frequencies but above audibility. An oscillatory circuit is provided resonant to this last frequency in which the signal is detected and reproduced for translation.







NUMBER 1,465,932—Multiplex Radio Telegraph System



NUMBER 1,465,961—Radio Signaling System

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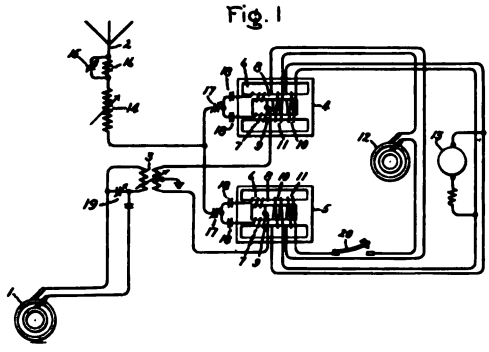
1,465,962—E. F. W. Alexanderson, filed April 19, 1916, issued August 28, 1923. Assigned to General Electric Company.



NUMBER 1,465,962—Radio Signaling System

RADIO SIGNALING SYSTEM for transmission of signals for reception free of the effect of static disturbances. The transmitter is provided with a source of sustained oscillations which is impressed on a divided antenna circuit. A magnetic amplifier is connected in each branch circuit, each opposite to the other, and both modulated from a source of lower frequency in such manner that signaling wave of two frequencies are emitted from the antenna system upon closing the controller circuit. One frequency may be higher than the main source by an amount equal to the frequency of the lower frequency generator and the other transmitting frequency may be higher than the main frequency by an amount equal to the lower frequency generator.

1,465,997—H. C. Rentschler, filed February 27, 1919, issued August 28, 1923. Assigned to Westinghouse Lamp Company.

ELECTRON TUBE APPARATUS for receiving circuits. A tube is described having its container filled with a medium exhibiting the phenomenon of resonance, that is, a medium in which electronic displacement occurs without the removal of an electron. The patentee points out that a particular gas or vapor has a certain resonance potential, that is, potential thru which the colliding electron must fall to acquire the necessary velocity to produce electronic displacement in the atomic system. Argon gas and certain metal vapors are described as exhibiting this phenomenon.

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1,465,998—H. C. Rentschler, filed February 27, 1919, issued August 28, 1923. Assigned to Westinghouse Lamp Company.

DETECTOR TUBE, wherein the electrodes are contained in a medium exhibiting the phenomenon of resonance, that is, an atmosphere such as argon, with sources of potential so connected that the anode is maintained positive with respect to the cathode and the grid or screen is maintained positive with respect to the cathode and anode. The potential on the grid is so adjusted that the plate current is at a maximum or minimum value because of the effect of electron reflection or secondary emission from the anode. The grid is connected in the receiving circuit so that the potential thereon is modulated with respect to the cathode.

1,466,263. E. F. W. Alexanderson, filed April 10, 1922, issued August 28, 1923. Assigned to General Electric Company.

RADIO FREQUENCY SIGNALING SYSTEM employing an electron tube generator which is capable of producing oscillations of both audio and radio frequency. The apparatus is adjusted and arranged in such a way that radio frequency oscillations will be produced only during a portion of each cycle of the audio frequency oscillations. By proper adjustment of the apparatus the radio frequency oscillations produced may be made of substantially constant amplitude during the period when they are being produced. Radio frequency oscillations produced by this arrangement have a high decrement permitting more efficient signaling than in the case of modulated radio frequency oscillations.

1,466,841—L. Levy, filed August 7, 1920, issued September 4, 1923.

ANTI-PARASITIC SELECTING SYSTEM for radio reception. The receiving system is provided with an artificial line tuned to the frequency of a long wave train vibrating in stationary waves. The circuit has a number of elements for causing a short wave train to give only a free wave. A pair of thermionic valves are arranged in series in reverse directions and connected in series in the artificial line at the nodes of the current and in shunt at the nodes of the stationary wave for suppressing undesired parasitic currents from the receiving apparatus.

1,467,154—J. H. Hammond, Jr., filed June 7, 1912, issued September 4, 1923.

SYSTEM OF RADIO DIRECTIVE CONTROL, wherein a body rota-

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table about a predetermined axis carries a motor which is caused to revolve in either one direction or an opposite direction selectively depending upon the relative position of the transmitting station and the body to be controlled.

1,467,318—W. J. Herdman, filed August 17, 1920, issued September 11, 1923.

ELECTRON DISCHARGE DEVICE which does not employ a third electrode or grid interposed between the anode and cathode to achieve a modulation of the space or thermionic current. In lieu of grid control, the phenomonen of magnetostriction is utilized to effect a movement of the anode or plate with respect to the cathode or filament thereby to decrease or increase the distance between the filament and plate and likewise to decrease or increase the effective plate area to produce an extremely wide variation of the plate current.

1,467,398—E. E. Schumacher, filed March 19, 1920, issued September 11, 1923. Assigned to Western Electric Company, Incorporated.

PROCESS OF COATING for a thermionic cathode of an electron tube. A base metal core is dipped in a molten bath of alkaline earth hydroxide. The core may be iron, tungsten, molybdenum, carbon and alloys of chromium or tantalum, which becomes thermionically active as a result of the coating derived from the bath and the aklaline earth hydroxide.

1,467,776—P. E. Demmler, filed January 16, 1919, issued September 11, 1923. Assigned to Westinghouse Electric and Manufacturing Company.

CONDENSER AND METHOD OF MAKING THE SAME, in which a strip of metal foil is coated with varnish which is first dried and then the strip wound with an uncoated strip about a pair of plates of insulating material with the inner ends of the strips spaced from each other between the plates. One of the condenser strips is of different width then the other and they are substantially insulated from each other by the coating of hardened varnish which is supplied over the wider strip.

1,467,777—P. E. Demmler, filed February 15, 1919, issued September 11, 1923. Assigned to the Westinghouse Electric and Manufacturing Company.

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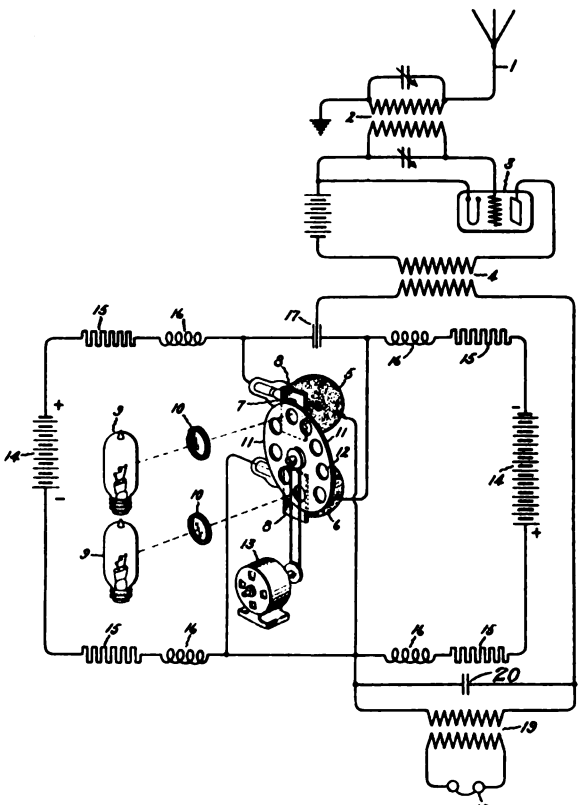
CONDENSER AND METHOD OF MAKING THE SAME, in which the condenser is built up of a plurality of alternate strips of metal foil and strips of flexible self-sustaining sheets of hardened varnish. The strips of metal foil are disposed in staggered relation so that the edges of alternate foil sheets project from the opposite sides of the completed unit, which is then embedded in wax.

1,467,988—C. A. Hoxie, filed March 16, 1922, issued September 11, 1923. Assigned to General Electric Company.



NUMBER 1,467,988—Radio Frequency Signaling System

RADIO FREQUENCY SIGNALING SYSTEM for continuous wave operation. A receiver is employed which has a circuit containing a light sensitive device or devices which has the property of permitting current to flow therethru when an electrode thereof is subjected to the influence of light. A rotating shutter is provided for varying or interrupting the illumination of this device

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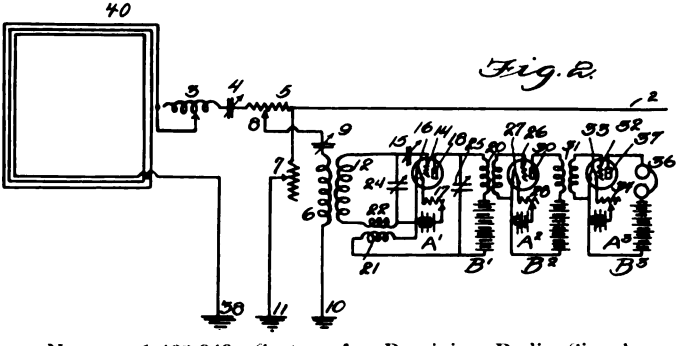
in such a way that the signaling current flowing in the circuit may be interrupted periodically in a predetermined desired manner and a rectifying effect may thereby be produced which will cause the current flowing in the circuit to be capable of operating a suitable form of indicator.

1,468,049—A. H. Taylor, filed October 9, 1918, issued September 18, 1923. Assigned to Radio Corporation of America.



NUMBER 1,468,049—System for Receiving Radio Signals

SYSTEM FOR RECEIVING RADIO SIGNALS, in which a pair of opposed collectors of the incoming signal energy are employed with a circuit arranged between the collectors for balancing out strays. One collector may be in the form of a loop and the other an extended ground wire. One end of the loop may be connected with ground and the other end through a phase-adjusting device in circuit with a resistance with the opposite extended conductor. A high ohmic resistance is connected to ground and to the junction of the extended conductor with the phase-adjusting circuit. The receiving apparatus is connected between the phase-adjusting circuit and ground. The collectors have an inherently different signal—stray ratio enabling them to be balanced one against the other, eliminating the strays and retaining the signal.

1,468,059—R. A. Weagant, filed February 7, 1919, issued September 18, 1923. Assigned to Radio Corporation of America.

METHOD AND APPARATUS FOR RADIO SIGNALING for eliminating static interference in radio reception. A pair of collecting systems is provided. One portion of the antenna system is so positioned with respect to the horizontal plane and relatively to the direction of the transmitting station as to collect substan-

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tially static only, while both static and signals are collected in the other portion of the antenna system. The currents due to static in the two antenna portions are opposed and balanced out while retaining the signals.

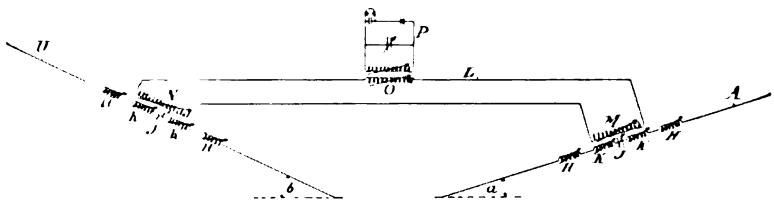
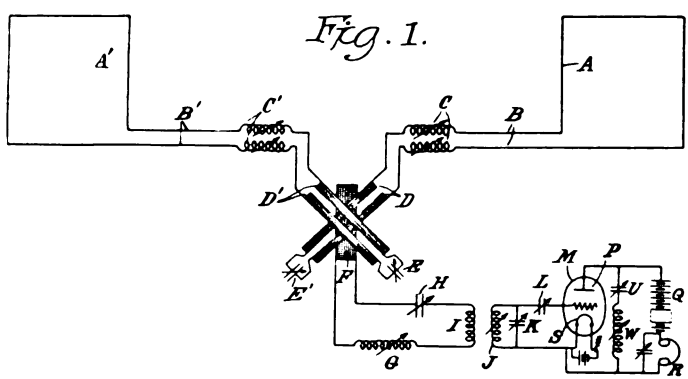


Fig. 2

NUMBER 1,468,059—Method and Apparatus for Radio Signaling

1,468,060—R. A. Weagant, filed July 19, 1917, issued September 18, 1923. Assigned to Radio Corporation of America.



NUMBER 1,468,060—Process and Apparatus for Receiving Radio Signals

PROCESS AND APPARATUS FOR RECEIVING RADIO SIGNALS, free from interference due to strays. The receiving system has a plurality of antennas separated by an appreciable fraction of a wave length and connected to coupling coils which are arranged in non-inductive relation to each other. The receiving circuit is connected to a third and independent coupling coil in inductive relation to both of the other coils.

1,468,061—R. A. Weagant, filed February 7, 1919, issued September 18, 1923. Assigned to Radio Corporation of America.

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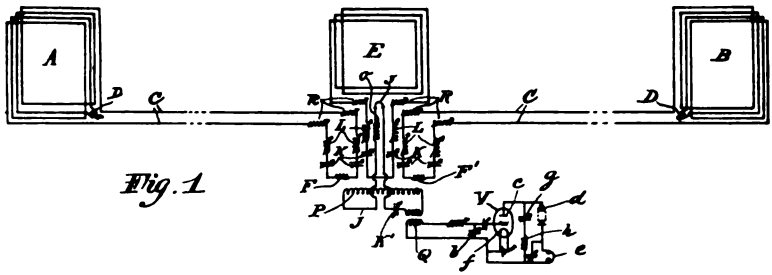

Fig. 1

NUMBER 1,468,061—Method and Apparatus for Radio Signaling

METHOD AND APPARATUS FOR RADIO SIGNALING, for minimizing the effects of static disturbances. A plurality of antennas are utilized. The system is tuned to the signal frequency and signal effects substantially eliminated while retaining the static. In another portion the signal effects and some static effects are received. The static effects in the first portion are then utilized to neutralize static effects in the second portion, leaving the signal effects which are amplified and observed.

1, 468,062—R. A. Weagant, filed July 12, 1918, issued September 18, 1923. Assigned to Radio Corporation of America.

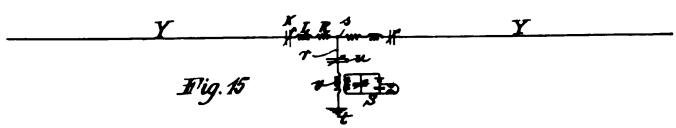

Fig. 15

NUMBER 1,468,062—Radio Signaling Apparatus

RADIO SIGNALING APPARATUS for reducing interference of static disturbances. A plurality of antennas are provided, tuned to the same wave length but having different ratios of static strength. A circuit common to the antenna systems is provided for balancing out the static while retaining the signal.

1,468,116—I. Langmuir, filed December 10, 1914, issued September 18, 1923. Assigned to General Electric Company.

METHOD OF AND MEANS FOR AMPLIFYING POTENTIAL VARIATIONS without responding to the effects of static. In the operation of a receiving system arranged in accordance with this invention all of the potential variations of the received waves of radiant energy on a strongly damped antenna may be amplified in their proper proportions. The amplified potential variations thus obtained may be impressed upon a current-limiting device which

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will eliminate all of the current impulses above a predetermined value and in this way the effect of heavy static discharges may be avoided. After the large impulses have thus been removed, suitable tuning apparatus may be employed to select the impulses of the frequency sent by the station from which it is desired to receive.

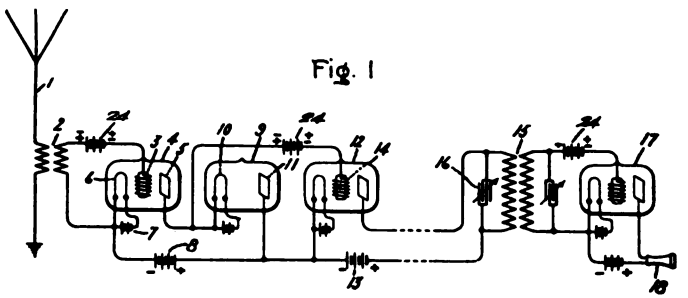

Fig. 1

NUMBER 1,468,116—Method of and Means for Amplifying Potential Variations

1,468,250—S. O. E. T. Trost, filed June 21, 1921, issued September 18, 1923. Assigned to Radio Corporation of America.

TRANSMITTER FOR RADIO TELEPHONY, in which two or more sets of oscillations are set up in different circuits which normally tend to neutralize each other. A microphone is arranged in one of the circuits for varying the relative phases of the oscillations for the production of the signals which are radiated from an antenna system.

1,468,653—C. D. Tuska, filed July 30, 1923, issued September 25, 1923.

CONDENSER of inexpensive construction comprising a fixed plate and a rotatable plate. Each plate is constructed of a thin metallic semi-circular foil sheet interposed between a pair of flexible circular sheets which may be paper stock. One of the disks is rotatable with respect to the other for varying the mutual position of the semi-circular foil sheets.

1,469,075—H. E. Dunham, filed March 23, 1921, issued September 25, 1923. Assigned to General Electric Company.

ELECTRON DISCHARGE APPARATUS for receiving continuous wave signals. An electron tube circuit is shown having a tuned circuit between the cathode and controlling grid. Oscillations are produced which automatically cause the grid to vary in poten-

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tial periodically at the frequency of the oscillations produced. A constant positive potential is impressed upon anode 3, and a smaller positive potential on third electrode 4. Secondary electrons are emitted from third electrode 4 which are attracted to anode 3. The normal operating potential of the third electrode 4 is such that an increase thereof will cause a decrease in the number of secondary electrons which will be given off from the third electrode.

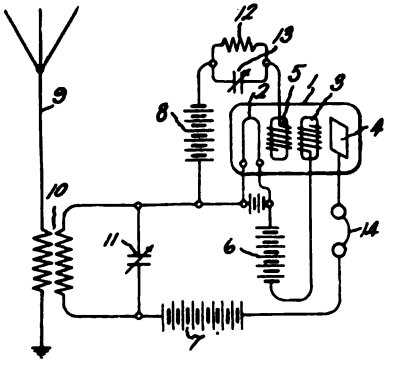

Fig. 1.

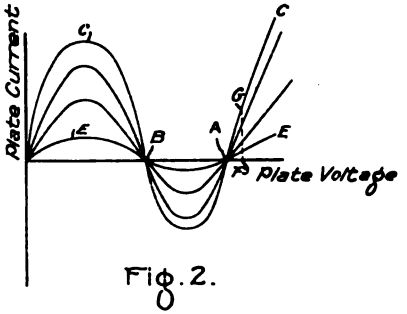

Fig. 2.

NUMBER 1,469,075—Electron Discharge Apparatus

1,469,328—E. Mayer, et al, filed August 3, 1922, issued October 2, 1923. Assigned to Gesellschaft für drahtlose Telegraphie m.b.H., Hallesches of Berlin, Germany.

CIRCUIT ARRANGEMENT FOR RECEIVING RADIO ENERGY in which an electron tube is connected with both the primary circuit and the secondary circuit. Either tube may generate oscillations and serve as a detector, and in determining the proper wave length either tube circuit may be used. When the proper wave length is chosen, the tube circuit connected with the secondary may be used for reception while the tube circuit associated with the primary is used as an oscillator for reducing the apparent resistance of the primary circuit for the frequency being received, thereby reducing the damping of the received energy.

1,469,349—A. L. Wilson, filed April 1, 1921, issued October 2, 1923. Assigned to Westinghouse Electric and Manufacturing Company

RADIO CONTROL SYSTEM for operating an electromagnetic

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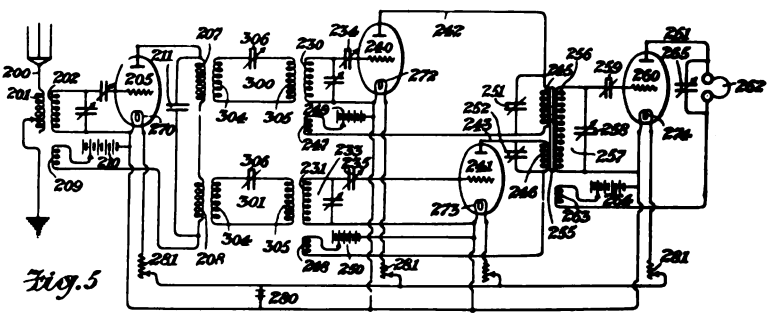
switch or a relay from a distant point. The transmitter is arranged to effect the radiation of a plurality of groups of waves having different wave lengths, each group of which is modulated in a predetermined series of impulses. The receiving system is provided with a rotary switch for varying the tuning to permit the reception of the different groups of waves which operated upon the receiver for selectively closing a circuit.

1,469,561—M. R. Hutchinson, filed January 21, 1920, issued October 2, 1923.

SIGNAL RECORDING AND TRANSCRIBING METHOD AND APPARATUS in which the signals are transmitted at a high rate of speed at a low tone frequency of the order of 320. At the receiver the signals produce a note at least three times as high as is required for phonographic reproduction. The signals are then recorded on a phonograph and then transcribed at a speed approximately one-third the recording speed. The object of the invention is to provide a method of transmitting signals at high speed for reception on a phonograph and transcription at a slow speed. The patentee points out that ordinarily the slowing down of the phonograph for transcription so lowers the tone frequency that it becomes confused with the normal scratching of the phonograph.

1,469,889—E. L. Chaffee, filed April 25, 1918, issued October 9. 1923. Assigned to John Hays Hammond, Jr.



NUMBER 1,469,889—Receiving System for Radiant Energy

RECEIVING SYSTEM FOR RADIANT ENERGY, adapted to receive waves of radio frequency having impressed thereon a series of periodic variations of a different frequency or a plurality of series of periodic variations of frequencies different from each other and

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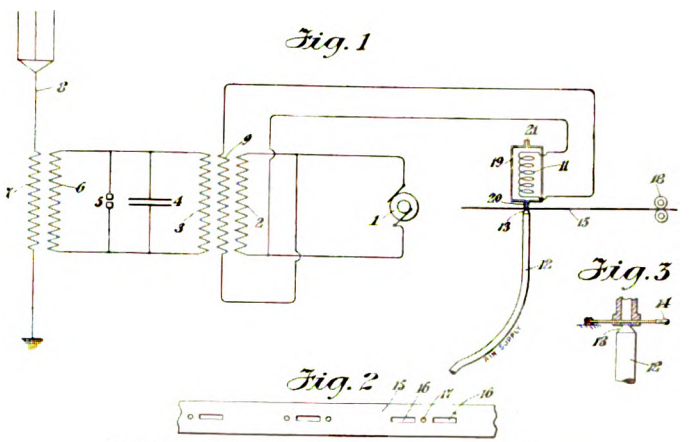
from the radio frequency for improving the selectivity of reception. The selectivity is secured in the receiving circuit by means of an initial circuit responsive to the working predetermined frequency, a modulator for developing therefrom a secondary frequency with a local generator having a frequency differing from the secondary frequency arranged to produce beats which operate the responsive device.

1,469,905—R. E. Hall, filed August 13, 1919, issued October 9, 1923. Assigned to Hall Research Corporation.



Number 1,469,905—Circuit Controlling Means

Circuit Controlling Means for a radio transmitter. The transmission of signals takes place automatically from a perforated dot and dash tape which passes adjacent a compressed ait jet opposite a heating coil. The spaces in the tape enable the jet to act upon the coil to cool the coil, which decreases its resistance momentarily. The coil is arranged in a circuit to modulate the transmitter for emitting wave trains in accordance with the cooling of the coil.

1,470,088—F. Lowenstein, filed November 29, 1918, issued October 9, 1923. Assigned to William Dubilier, of New New York.

Art of Communication utilizing audio frequencies as distinguished from radio frequencies for transmission of signals. A multiple frequency generator of any one of several frequencies below 10,000 cycles is provided at the transmitter

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in combination with a switching arrangement for selectively energizing the primary of a step-up transformer. The secondary of the transformer is sharply tuned and delivers audio frequency energy to the antenna system for transmission.

1,470,781—P. Thomas, filed October 3, 1917, issued October 16, 1923. Assigned to the Westinghouse Electric and Manufacturing Company.

ROLLED CONDENSER in which the condenser structure is built up with a plurality of leads for each pole of the condenser and the structure impregnated and then all of the similar leads comprising each pole spot welded firmly, connecting the condenser plates of similar polarity.

1,470,955—W. E. Booth, filed November 22, 1919, issued October 16, 1923. Assigned to Western Electric Company, Incorporated.

ELECTRICAL WAVE TRANSMISSION SYSTEM for transmitting and receiving, wherein a signle switching element is used in the antenna circuit for changing from transmission go reception. The apparatus comprising both the transmitter and the receiver is compactly arranged. The direct current used in the microphone circuit is obtained from the same electrical source which is used for one or more other purposes in the system. During transmission one of the receiver amplifying tubes is connected in the microphone circuit.

1,471,165—L. L. Israel (now by judicial change of name L. L. Jones), filed July 19, 1920, issued October 16, 1923.

RADIO RECEPTION in which desired signals are received to the exclusion of disturbances of all kinds resulting from waves or pulses of relatively high damping or from waves differing in frequency from the signal waves. Two antennas having low damping and approximately the same electrical characteristics are employed. The antennas are set in close proximity to receive in the same direction. Electroststic shields are provided to eliminate transfer of energy between the antennas. One antenna is tuned to the signal wave and the other slightly detuned therefrom. The currents generated in the antennas are rectified and the opposing forces combined, operating an indicator by the resultant force.

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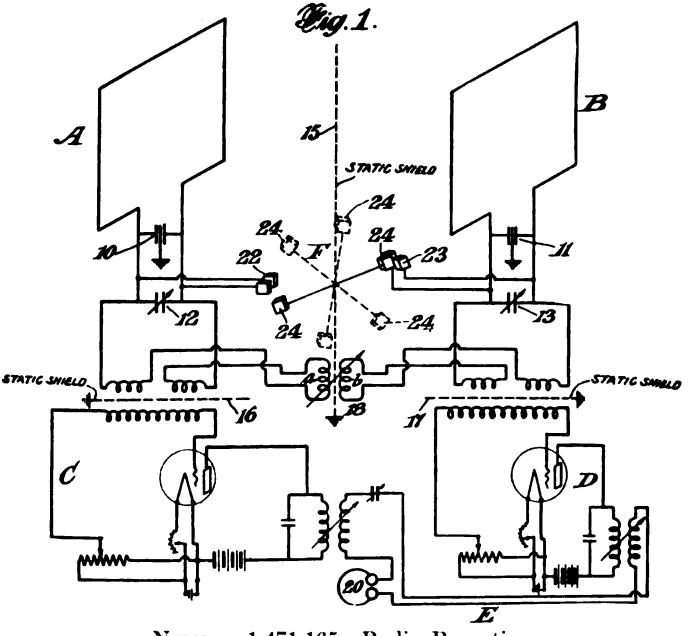
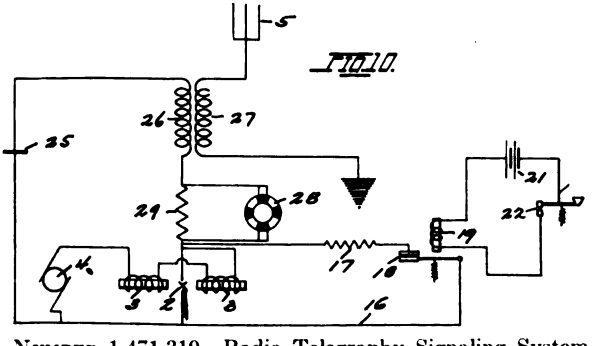


NUMBER 1,471,165—Radio Reception

1,471,319—H. Pratt and E. B. Murphy, filed January 3, 1921, issued October 16, 1923. Assigned to A. Taylor, of San Francisco, California.



NUMBER 1,471,319—Radio Telegraphy Signaling System

RADIO TELEGRAPHY SIGNALING SYSTEM, using the arc generator as a source of sustained oscillations at the transmitter. The antenna circuit is arranged to be modulated at an audio frequency, thereby breaking up the continuous wave into time-spaced groups at such a frequency that the group frequency is

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within the range of audibility. An energy-consuming circuit is alternately inserted and withdrawn in the arc oscillatory circuit at an audio rate whereby the arc is extinguished and re-ignited at this rate.

1,471,342—L. Logan, filed April 30, 1920, issued October 23, 1923.

MEANS FOR CONTROLLING PROCESSES OF PRODUCTION by radiant energy. The invention refers to a variety of production processes wherein an inanimate material during its process of manufacture undergoes some change which may be brought about by radiant energy control. The patentee mentions the manufacture of sulphuric acid and the application of radiant energy control means for indicating existence of constituents or progress of said manufacture.

1,471,406—F. S. McCullough, filed July 25, 1919, issued October 23, 1923. Assigned to Glenn L. Martin, Cleveland, Ohio.

RADIO TELEGRAPHY receiving system wherein the direction of a transmitting station is determined by a visual indication of the strength of the received signals. The system is particularly described as applied to a direction finder on air craft where the audible method of determining direction by radio bearings is subject to interference from machine noises. The directional antennas used in the system are encased in evacuated tubes.

1,471,418—J. F. Rodgers, filed May 26, 1922, issued October 23, 1923. Assigned one-half to Charles Hanselmann, Brooklyn, New York.

TUNING TRANSFORMER utilizing a pair of slides along a greater and a smaller coil provided with a slide with connections for placing an accurate number of turns of the coil in the tuning circuit.

1,471,756—W. B. Schulte, filed October 17, 1919, issued October 23, 1923. Assigned to Burgess Battery Company, Wisconsin.

WAVE SIGNALING SYSTEM utilizing a "B" battery construction for the electron tube circuit in which the battery comprises a case, a nest fitted therein, a set of vertical cells arranged in the nest and spaced at their lower ends from the bottom of the case a water-repellant wrapper completely encasing each cell, and a seal anchoring the cells in said nest and the wrappers to said cells.

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List of Radio Trade Marks Published by Patent Office Prior to Registration

(The numbers given are serial numbers of pending applications)

164,075—"Radioceive" for telephone head sets, Radioceive Mfg. Co., Newark, New Jersey. Claims use since April 1, 1922. Published September 4, 1923.

169,814—Musical design for radio apparatus; Walter Lytton, Inc., Chicago, Illinois. Claims use since about January, 1922. Published September 4, 1923.

175,712—Letter "C" in ornamental design, for radio receiving sets; Continental Radio and Electric Corporation, New York City. Claims use since August 1, 1922. Published September 4, 1923.

178,612—"The Jiffy Clips"—electrical connector clips for radio use; Herbert M. Hill, Leonia, New Jersey. Claims use since on or about December, 1922. Published September 4, 1923.

180,953—"Na-ald" for radio apparatus; Alden Mfg. Co., Springfield Massachusetts. Claims use since April 1, 1923. Published September 4, 1923.

173,721—"Reflex" for radio apparatus; Wm. H. Priess, New York City. Claims use since April 18, 1922. Published September 18, 1923.

163,608—"Air Line B-R" in ornamental design for adapters for connecting a receiver with a phonograph amplifying chamber. The Beckley-Ralston Co., Chicago, Illinois. Claims use since April 10, 1922. Published October 9, 1923.

176,792—"Tesco" in ornamental design for radio receiving apparatus. The Eastern Specialty Company,Philadelphia, Pennsylvania. Claims use since January 2, 1922. Published October 9, 1923.

179,091—"Variohm" in ornamental design for rheostats and grid leaks. Electrad Corporation of America, New York City. Claims use since Fenruary 1, 1923. Published October 9 1923.

179,364—"Acmedyne" for radio receiving sets. Danziger-Jones, New York City. Claims use since April 9, 1923. Published October 9, 1923.

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180,705—"K" in ornamental coat of arms for radio receiving apparatus. Colin B. Kennedy Co., St. Louis, Missouri. Claims use since April 1, 1923. Published October 9, 1923.

181,000—"AERADIO" in ornamental design for radio receiving apparatus. Charles A. Brichfield, New York City. Claims use since April 1, 1922. Published October 9, 1923.

182,271—"MONOTROL" for radio receiving apparatus. Sleeper Radio Corporation, New York City Claims use since April 23, 1923. Published October 9, 1923.

182,606—"PIONEER RADIO CORPORATION" in ornamental design for variometers and variocouplers. Pioneer Radio Corporation, Galesburg, Illinois. Claims use since April, 1922. Published October 9, 1923.

183,162—"HEGEHOG" for audio frequency transformers. Premier Electric Company, Chicago, Illinois. Claims use since May 1, 1923. Published October 9, 1923.

151,150—"ESCO" in ornamental design for radio apparatus. Electrical Specialty Co., Columbus, Ohio. Claims use since March 1, 1920. Published October 23, 1923.

179,466—"ANC-HOR-ITE" for crystal detectors. The Anchor Company, Pittsburgh, Pennsylvania. Claims use since March 15, 1923. Published October 23, 1923.

181,439—"ERMCO LITE" in ornamental design for radio apparatus. Electric Regulator Mfg. Corporation, New York City. Claims use since April 21, 1923. Published October 23, 1923.

181,572—"MUSIC MASTER" in ornamental design for loud speakers. Sheip and Vandergrift, Inc., Philadelphia, Pennsylvania. Claims use since November 9, 1922. Published October 23, 1923.

182,353—"LITTLE TATTLER" for headsets. Marinette Electric Corporation, Marinette, Wisconsin. Claims use since May 1, 1923. Published October 23, 1923.

166,344—"BALDWIN" in ornamental design for radio apparatus; Baldwin Radio Electrical Mfg. Co., Inc., Brooklyn, N. Y. Claims use since March 28, 1922. Published October 30, 1923.

175,226—"VARIO-WAVE" for variocouplers and variometers.

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G. H. Fischer & Co., Glendale, Long Island, New York. Claims use since August, 1922. Published October 30, 1923. Not subject to opposition.

175,332—"CONCERT GRAND" in ornamental design for radio receiving apparatus. True-tone Radio Mfg. Co., Chicago, Illinois. Claims use since February 28, 1922. Published October 30, 1923. Not subject to opposition.

181,254—Circular spot of red for plugs for use with radio apparatus. Dubilier Condenser and Radio Corporation, New York City. Claims use since April 26, 1922. Published October 30, 1923.

176,887—"TESCO" for radio apparatus. The Eastern Specialty Company, Philadelphia, Pennsylvania. Claims use since September 17, 1915. Published October 30, 1923.

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PROCEEDINGS of The Institute of Radio Engineers

EDITED BY
ALFRED N. GOLDSMITH, Ph.D.

PUBLISHED EVERY TWO MONTHS BY
THE INSTITUTE OF RADIO ENGINEERS
THE COLLEGE OF THE CITY OF NEW YORK
140th Street and Convent Avenue, New York, N. Y

Subscription $9.00 per Annum in the United States
$9.60 in all other Countries

GENERAL INFORMATION AND SUBSCRIPTION RATES ON PAGE 1

Entered as second-class matter, February 16, 1916, at the Post-Office, at New York, N. Y., under the Act of March 3, 1879.

Acceptance for mailing at special rate of postage provided for in Section 1103, Act of October 3, 1917, authorized October 7, 1918.

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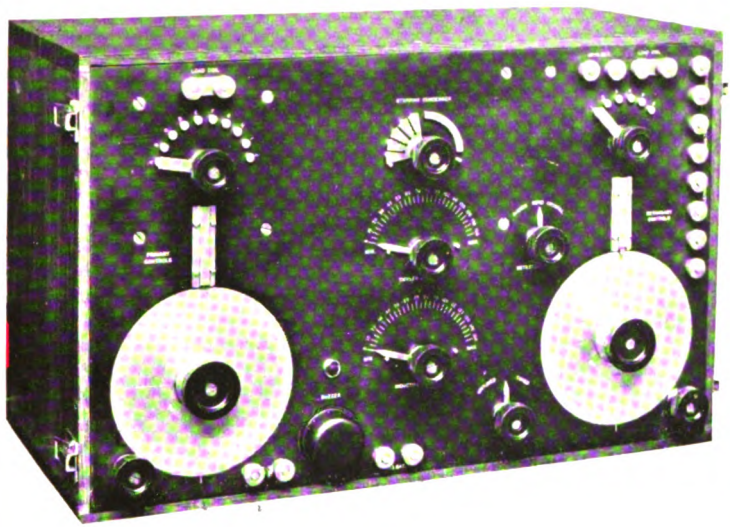
"Receiver, IP 500"



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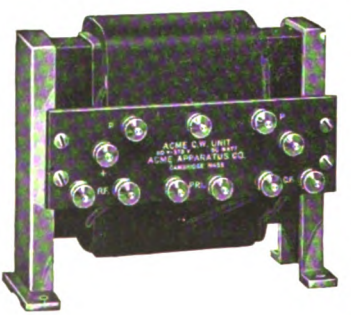

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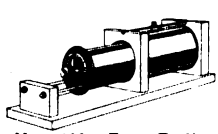

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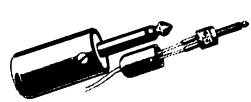
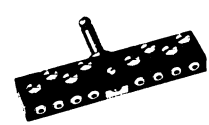


No. 137—Frost Radio Cord Tip Plug.



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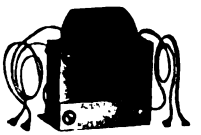

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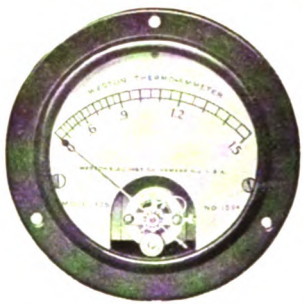

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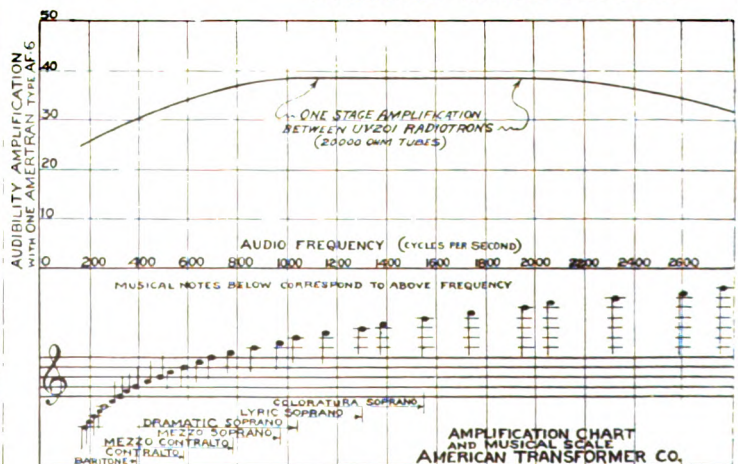

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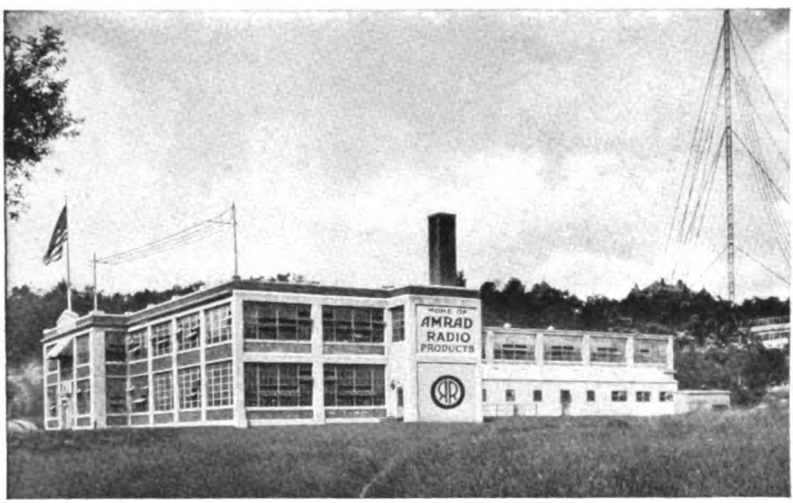

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Radion is a special quality of hard rubber developed exclusively for radio use. It possesses certain mechanical, electrical and other physical advantages which distinguish it as superior to other mouldable materials, of whatever nature, offered for use in the radio industry for panels or moulded parts. Exhaustive tests made at the Electrical Testing Laboratories (New York), than whom there is no more capable or unbiased authority, in competition with twelve other standard materials offered, have established the fact that—

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Radion sheets are made in a range of standard sizes, while special sizes are supplied on quantity orders. There are two standard thicknesses, 3-16 and 1-4 inch, and three stock colors—black, brown and mahoganite (mahogany grain).

Radion standard moulded parts include Dials, Knobs, V-T Sockets, Variometer Tubes and Rotors, Aerial Insulators. Special moulded parts are made to order for manufacturers, as Phone Ear Caps and Cases, Condenser Sides, Bases, Antenna Plug Parts, Buttons, Switch Handles, etc.

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American Hard Rubber Company

11 MERCER STREET, NEW YORK, N. Y.
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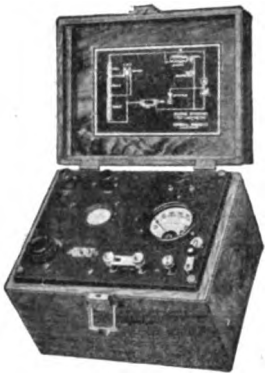
WAVE METER



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RANGE 150–3000 METERS

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Particular care has been given to the mechanical construction and to the appearance of this instrument. All of the equipment is mounted on a bakelite panel and enclosed in a polished walnut carrying case. The metal parts are finished in polished nickel.

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Radio and Electrical Laboratory Apparatus

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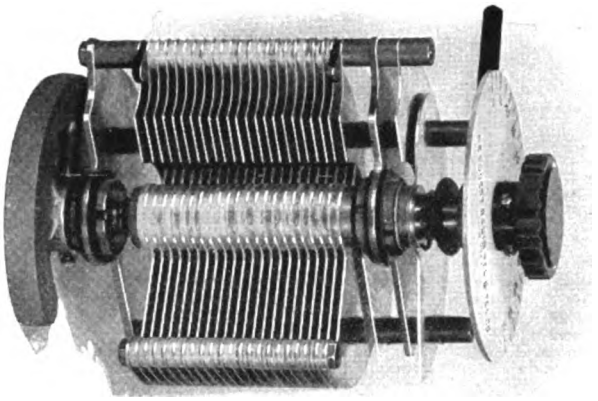

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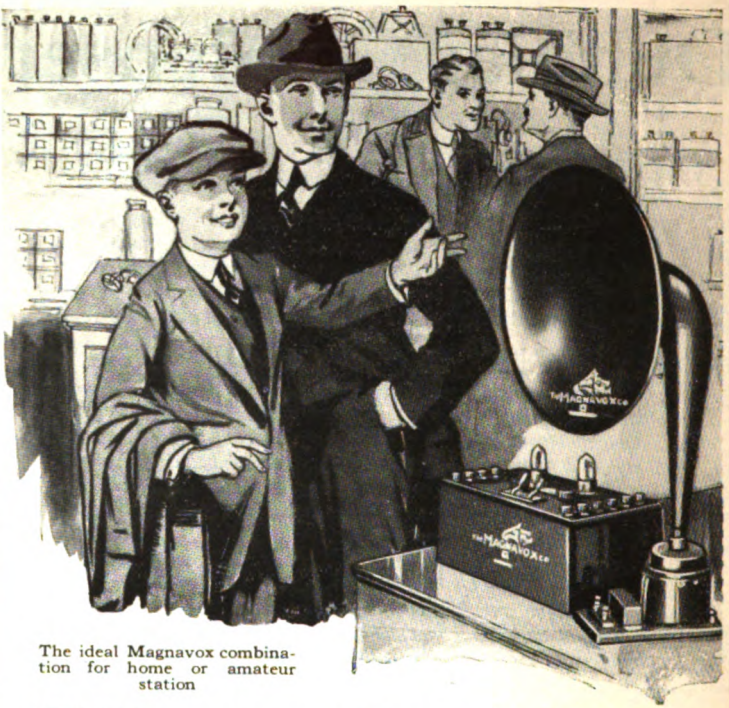

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VOLUME 11 DECEMBER, 1923 NUMBER 6

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PROCEEDINGS
of
The Institute of Radio Engineers

EDITED BY
ALFRED N. GOLDSMITH, Ph.D.

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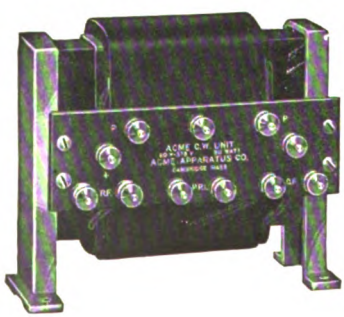

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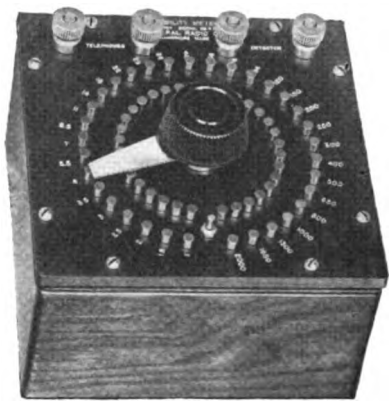

Type 164

AUDIBILITY METER

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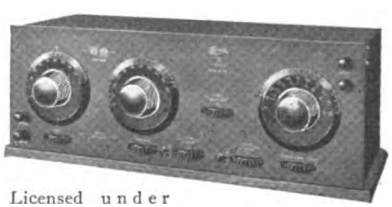

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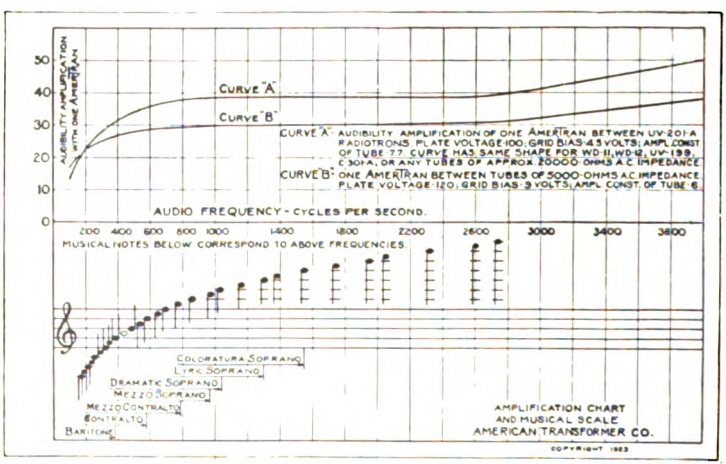
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CURVE "B"
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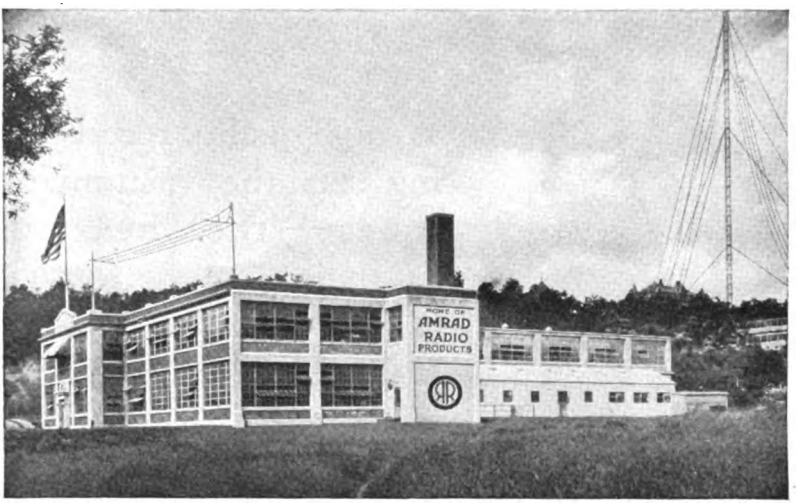

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AMERICAN RADIO AND RESEARCH CORPORATION

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Radiotron WD-11
Radiotron UV-199
Radiotron WD-12
Radiotron UV-200
Radiotron UV-201-A

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The PROCEEDINGS now carries a Professional Engineering Directory (see advertising page XIV) for the use of radio and consulting engineers and organizations rendering testing or engineering construction service. A card in this section costs only $5.00 per issue, or $25.00 per year on contract. For further particulars address

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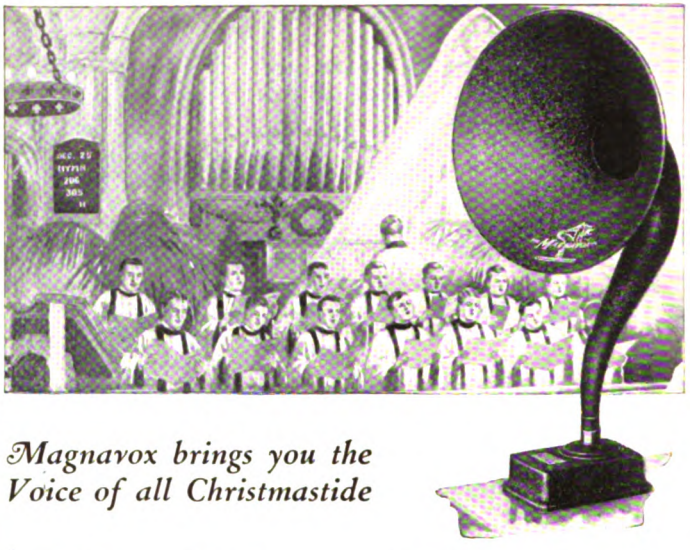

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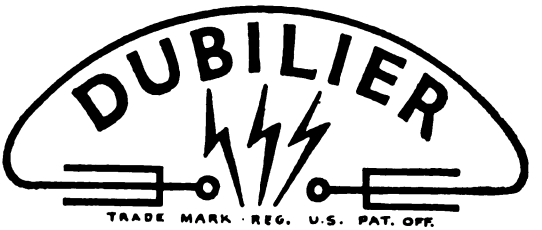

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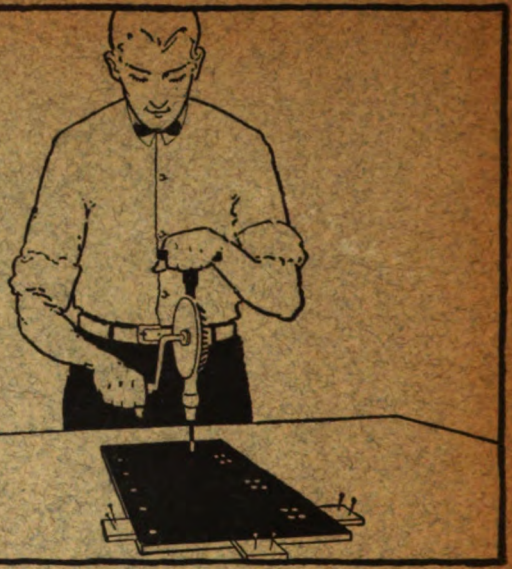

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